Isokinetic peak torque values of the knee and shoulder joint in university rowers

A research dissertation presented to the Faculty of Health Sciences, University of Johannesburg, in fulfilment of the M Phil Degree in Biokinetics

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Professor: L Lategan (supervisor): ___________________________

Date: ________20/09/2019________________

TABLE OF CONTENTS

DECLARATION

I, Kirsten Sarah Nolan, declare that this dissertation is my own, unassisted work. It is being submitted to the University of Johannesburg in fulfilment of my Master's degree in Biokinetics. It has not been submitted for any degree or examination to any other University.

Kirsten Sarah Nolan

On the_day of the month ___________17 July_______2019

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Herewith declare that my academic work is in line with the Plagiarism Policy of the University of Johannesburg. I further declare that the work presented in this dissertation ISOKINETIC PEAK TORQUE VALUES OF THE KNEE AND SHOULDER IN UNIVERSITY ROWERS is authentic and original, and there is no copyright infringement in the work. I declare that no unethical research practises were used or material gained through dishonesty. I understand that plagiarism is a serious offence.

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This affidavit conforms to the requirements of the JUSTICES OF THE PEACE AND COMMISSIONERS OF OATHS ACT 16 OF 1963 and the applicable regulations published in the GG GNR 1258 of 21 July 1972, GN 903 of 10 July 1998, GN 109 of 02 February 2001 as amended.

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ABSTRACT

Purpose: The main aim of this study was to assess bilateral isokinetic peak torque (PTQ) in the knee and shoulder joint of university rowers. A secondary aim was to examine possible bilateral muscle imbalances and to compare the males to the females in terms of PTQ produced.

Method: The research design was a descriptive, quantitative study. The population of the research were university rowers in Gauteng. The research sample included rowers that were part of a university rowing club in Gauteng (n=37). Sampling included male and female rowers ranging between the ages of 18 and 35 years. All participants who consented to participate completed a PAR-Q and a comprehensive medical history questionnaire. Knee flexion and extension, shoulder internal (IR) and external rotation (ER) were assessed using the Humac Norm Isokinetic Dynamometer at 60°/sec, using a concentric-concentric (CON-CON) and eccentric-eccentric (ECC-ECC) contraction mode. Descriptive statistics (means, minimums, maximums and standard deviations) and non-parametric comparative statistics (Mann-Whitney U Test) were used to analyse the data. Statistical significance was set at $p<0.05$.

Results: Participants included 24 males (21.58 ±2.08 y) and 13 females (21.77 ±2.28 y). Significant differences were found between the dominant (DL) and non-dominant (NDL) CON and ECC knee extension PTQ at 60°/sec in male rowers (DL>NDL), but not in female rowers. However, in female rowers there were significant differences between the DL and the NDL for the eccentric hamstring/quadriceps (ECC H/Q) ratio and for CON and ECC shoulder IR and ER at 60°/sec (NDL>DL).A significant difference was also found for male rowers in CON PTQ for shoulder ER (DL>NDL), and ECC PTQ IR at 60°/sec (DL>NDL). Both CON knee H/Q ratio and CON shoulder ER/IR ratio at 60°/sec had no significant difference in DL and NDL for males and females ($p\geq0.05$). However, there were significant differences in the DL and NDL for ECC knee H/Q ratio at 60°/sec for female rowers (NDL>DL; $p=0.019$), as well as for ECC shoulder ER/IR ratio for male rowers (NDL>DL; $p=0.003$). There was also a significant difference observed between males and females for the DL shoulder ER/IR ratio ($p=0.002$).

Conclusion: The present study is the first to establish isokinetic reference values for the knee and shoulder muscles in South African university rowers. In addition, the results highlight the presence of significant muscle imbalances in both male and female rowers for CON and ECC knee flexion and extension, as well as for shoulder IR and ER.

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

°/sec: degrees per second

BFP: body fat percentage

BMI: body mass index

BW: body weight

cm: centimetre

CON: concentric

DL: dominant limb

ECC: eccentric

ER: external rotation

ER/IR: external rotation/internal rotation ratio (of the shoulder)

Ext: extension

Flex: flexion

H/Q: hamstrings/quadriceps ratio

i.e.: that is

IR: internal rotation

kg: kilogram

l/min: litres per minute

LBP: lower back pain

mm: millimetre

NDL: non-dominant limb

Nm: Newton metre

Nm/kg: Newton metre per kilogram

PTQ: peak torque

PTQ/BW: peak torque per body weight

ROM: range of motion

RPE: rating of perceived exertion

SD: standard deviation

VO_{2max}: maximum aerobic capacity

y: years

CHAPTER 1: INTRODUCTION

1.1 Introduction

Rowing is a whole-body exercise in which the movements of the upper and lower extremities must cooperate together. Rowing involves repetitive motion stressing various anatomical areas continually. Off-water training for rowing also involves similar repetitive activities, such as weight-lifting, running, stair running, cross-country and using a rowing ergometer. The majority of rowers suffer from different overuse injuries, for example, stress fractures (primarily affecting the ribs), lower back pain, anterior knee pain, iliotibial band (ITB) friction syndrome and shoulder pain (Smoljanovic, Bojanic, Hannafin, Hren, Delimar & Pecina, 2009). These injuries may be a result of overuse, poor technique, or other biomechanical abnormalities. Although injuries and pain are not of specific interest in this research study, it is important to note that muscle imbalances may possibly lead to injury and thus, negatively affect rowing performance (Wilson, Gissane & McGregor, 2014; Donatelli, Dimond & Holland, 2012).

1.2 Aim of the study

The main aim of this study was to assess bilateral isokinetic peak torque (PTQ) of the knee and shoulder joint in university rowers. A secondary aim was to examine possible bilateral muscle imbalances and to compare the males to the females in terms of PTQ produced.

1.3 Objectives

1.3.1 To assess the concentric (CON) and eccentric (ECC) isokinetic knee flexion-extension and shoulder external-internal rotation PTQ values of male and female rowers.

1.3.2 To compare the isokinetic knee flexion-extension and shoulder internal-external rotation PTQ values between male and female rowers.

1.3.3 To determine the possible presence of bilateral deficits in isokinetic knee flexion-extension and shoulder internal-external rotation PTQ between the dominant and non-dominant limbs of male and female rowers.

1.4 Possible benefits of study

The possible outcomes of this study include establishing reference values for CON and ECC isokinetic knee flexion-extension and shoulder internal-external rotation PTQ in competitive university rowers and to highlight possible muscle strength imbalances that may exist between the dominant and non-dominant limbs to play a role in the prevention of overuse injuries in rowers and to enhance their performance.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Rowing is an unusual sport in that the athletes sit facing the stern of the boat with their feet anchored in sneakers attached to a foot stretcher. Their backs are facing the finish line, and the bow of the boat crosses the finish line first (Hosea & Hannafin, 2012). It is a strength-endurance sport, challenging both the aerobic and anaerobic energy systems (Nolte, 2011:73). Competitive rowing consists of the athletes training more than six times a week, as well as competing in regattas locally, provincially and/or internationally. As with many other sports, the risk exists for developing muscle imbalances as a result of the unique training involved. These muscle imbalances may lead to overuse injuries and it may also negatively affect performance. Since isokinetic testing provides a valid and objective means of assessing muscle strength, it is one of the most reliable methods used to assess muscle strength.

2.2 Biomechanics of rowing

Rowing involves almost all muscles of the body (Yoshiga & Higuchi, 2003a & b), but the main feature that differentiates it from most sports is the simultaneous action of both legs during the technical execution of the stroke. Rowing biomechanics analyse technique to make it more effective by giving importance to both large and small kinetic and kinematic details (Baudouin & Hawkins, 2002). A high level of technique is essential to enable the effective transfer of force through the stroke (Buckeridge, Bull & McGregor, 2015). The aim to improve technique in rowing is to increase human propulsion engine and acceleration to boost the athlete's performance. During the drive, nearly half of the required power (46%) is contributed by legs, a third by the trunk (32%) and above a fifth (22%) by arms (González, 2014).

In rowing, the leg muscles serve as important contributors to the propulsion of the rowing boat by pushing against the footboard (Soper & Hume, 2004). Several studies have emphasized the major role of the quadriceps muscle group to produce power during the rowing stroke (Goodall, González-Alonso, Ali, Ross & Romer, 2012). Furthermore, approximately 70% of total muscle mass is involved since the upper and lower body muscles work synchronized during the rowing stroke (Steinacker, 1993). Rowers spend a lot of time on the water, training in a boat. There are two types of rowing on the water; scull and sweep. Sculling requires the rower to hold two blades, one in each hand. Sweep rowing requires the rower to hold one fairly large blade on either the left side of the boat (bow), or on the right side of the boat (stroke). There is a substantially increased amount of unilateral biomechanical load placed on the lumbar-pelvic region during sweep rowing. In addition to the flexion and extension, there is also a small amount of rotation to the side of the blade, placing further load on the lumbar-pelvic joints. These motion restrictions can result in localised pain, referred pain and abnormal biomechanics of the muscles which may influence posture, technique, ROM, as well as power output (Buckeridge, et al,. 2015; Ruffaldi & Filippeschi, 2012).

However, in sweep rowing or single-sided rowing there is still the synchronization between the upper and lower body, but the rower is required to rotate their trunk at the catch, causing the upper limbs to follow an asymmetrical arced trajectory, as well as positioning the rowers outside leg (leg opposite the blade) more laterally than the inside leg (Fenwick, Brown & McGill, 2009). Which is why sweep rowing will be the style of rowing focused on in this study.

The rowing stroke begins at the finish with the knees fully extended, the back in a laid-back position from vertical, with hips relatively extended and the elbows flexed into the body at waist height. The recovery phase begins with the movement of the hands away from the body toward the sternum of the boat, followed by forward flexion at the hip and the forward movement of the spine. When the body and shoulders are past the hips and the hands past the knees, the legs slowly begin to flex until the catch position is reached with the knees flexed approximately 110° to 120° (Hosea & Hannafin, 2012). The hip is maximally flexed, and the shoulders are fully extended. At this compressed position, there is a great deal of potential energy stored in the legs, back, and arms in preparation for the drive phase of the stroke. At the catch, the oar is placed into the water, followed by the legs driving the body back toward the bow of the boat, pulling the bow passed the anchored oar. The back, shoulder, and arms function as a braced cantilever so that the force generated by the legs can be applied to the oar and not dissipated. The drive phase ends at the finish, and the same cycle is repeated over and over for the length of the race or practice (Buckeridge, Hislop, Bull & McGregor, 2012). The rowing action has been divided into the following sequence: the catch, drive, finish, and recovery.

2.2.1. The Catch

The catch-phase involves forward flexion of the trunk and hips, and knee flexion, together with ankle dorsiflexion, while the shoulders are flexed and the elbows extended. During this phase the active muscles (contracting concentrically) include the abdominals, hip flexors, shoulder flexors and the triceps brachii, while their antagonists (contracting eccentrically) are less active (e.g. erector spinae and hip extensors). The psoas major and minor and the iliacus flex the pelvis and hips during this phase and the sartorius muscle rotates the thighs, which allows the body to flex further forward and thus obtain maximum reach, and the tibialis anterior muscle assist with ankle dorsiflexion. In the trunk and lower limbs the erector spinae, gluteus maximus, quadriceps and soleus muscles are elongated and stretched in an eccentric (ECC) contraction, while in the upper limb the latissimus dorsi, rhomboids and triceps brachii are also in an elongated position. This pre-stretch will allow the muscles involved to produce optimal CON muscle strength during the drive phase (Flood & Simpson, 2012).

2.2.2. The Drive

The initial portion of the drive demands maximal power from the legs. The quadriceps extend the knee, and the feet are plantar flexed by the soleus and gastrocnemius muscles. A number of stabilizing muscles aid in supporting the lower (Flood & Simpson, 2012).

All the muscles of the shoulder are contracting. These include the supra and infraspinatus, subscapularis, teres major and minor, and the biceps brachii. The scapula is stabilized by the serratus anterior and trapezius muscles. As the knees are finishing their extension, the hip is also extending by the contraction of the gluteus and hamstring muscles. Back extension is occurring by contraction of the erector spinae (Flood & Simpson, 2012).

In the upper body, elbow flexion is occurring via the biceps, brachialis, and the brachioradialis muscles (Flood & Simpson, 2012). The knees are maximally extended, and the ankles are plantar flexed. In addition, hip and back extension is being completed. The upper body musculature is contracting with high force to finish the drive. The elbow flexors are dominant. The flexor and extensor carpi ulnaris muscles of the forearm contract to stabilize and adduct the wrist. The shoulder is extended and adducted. The upper arm is internally rotated by the latissimus dorsi and pectoralis major. The teres minor, posterior deltoid and long head of the biceps are acting on the shoulder joint. The scapula is rotated downward by the pectoralis minor and then drawn backward by the trapezius and rhomboid muscles (Flood & Simpson, 2012).

2.2.3. The Finish

The knees and ankles remain constant as the hips complete a full extension. The back extensors are continually contracting, and the upper arms are internally rotated by the contracting latissimus dorsi. The triceps are extending the elbows slightly (Flood & Simpson, 2012).

2.2.4. The Recovery

The arms are pushed forward and away from the body by the triceps until the elbows reach full extension. The anterior deltoids contract along with the coracobrachialis and biceps, and the upper arms rise slightly as they pass over the extended knees. The abdominals flex the torso, and once the hands have cleared the extended knees, the slide begins its forward motion through ankle dorsiflexion and hip and knee flexion, where the hamstrings are in CON contraction and the quadriceps in ECC contraction (Flood & Simpson, 2012).

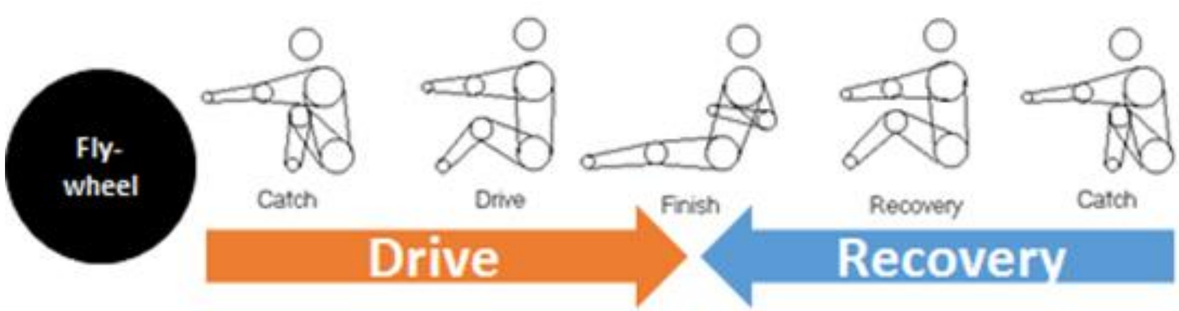

Figure 2.1 Demonstration of the rowing stroke (Monplaisir, 2015).

2.3 The Physiology of rowing

Anthropometric characteristics are a good predictor of performance in rowing (Akça, 2014; Mikaliç & Ruziç, 2008; Schranz, Tomkinson, Olds & Daniell, 2010). For example, height and body mass were significantly correlated with performance in rowing (Akça, 2014) and a study on elite male rowers revealed that rowers who were taller, heavier, stronger with more muscle mass and less body fat, were at an advantage in rowing. Literature suggests that elite rowers were heavier than less successful rowers. Secher (1993), Mikuliç (2009), Forjasz (2011), and Adhikari & Mcneely (2015) stated that the most successful male and female rowers were taller (192cm & 180cm) and heavier (92kg & 79kg), with a higher sitting height and a lower fat percentage than less successful rowers.

Men are generally faster than women for reasons that consist of anatomical and physiological sex differences including: larger and more powerful muscle mass (Jassen, Heymsfield, Wang & Ross, 2000; Mayhew & Salm, 1990; Stefani, 2006), higher maximal oxygen consumption (Joyner, 1993; Sparling, 1980), and increased biomechanical efficiency (Anderson, 1996; Zamparo, 2006). However, the differences between men and women in performance are greater than what would be expected due to anatomical and physiological differences alone. For example, sex differences in elite sport performance widen with finishing place in almost every sport previously studied (Jassen et al., 2000; Keenan, Senefeld & Hunter, 2018; Stefani, 2006).

Previous studies indicated that high-performance rowers were younger than low-performance rowers (23.80 ±4.06 years and 26.58 ±7.73 years respectively). This data was in agreement with several studies where high-performance Olympic rowers were between 20 and 24 years old (Akça, 2014; Lawton, Cronin, & McGuigan, 2013; Sanada, Miyachi, Tabata, Suzuki, Yamamoto, Kawano & Higuchi, 2009).

Another study found a negative correlation between rowing performance and body fat percentage (BFP). It is well established that increased BFP adversely affects 2000m rowing ergometer performance (Ingham, Carter, Whyte & Doust, 2002). Therefore, low BFP can be an advantage in rowing. A certain amount of fat is required for maintenance of body metabolism but excess adiposity has a negative influence on performance. Manore, Barr and Butterfield (2000) showed that BFP varies depending on the athlete's sex and the sport itself. Studies on male international rowers had noted that the range of BFP values was from 6% to 10% (Hagerman & Toma, 1997).

A study on female rowers and kayakers showed a range of 16% to 19% BFP (Sklad, Krawezyk & Majle, 1994). Rowers have some of the highest values for maximum oxygen consumption (VO_{2max}) of all elite athletes, as values between 6.0 l/min (Yoshiga & Higuchi, 2003a & b) and 6.9 l/min (Volianitis & Secher, 2009) have been reported.

Penichet-Tomasi, Pueo and Jimenez-Olmedo (2016) conducted a study on the relationship between experience and training characteristics of non-Olympic rowing modalities. For high-performance rowers, in-rigger is characterized by rowers who train significantly more days per week and more hours per day than low-performance rowers. On the other hand, high performance fixed seat rowers are significantly more experienced than low-performance rowers. Furthermore, they train significantly more days per week than low performance fixed seat rowers. They found that there is a direct relationship between these variables with performance in different modalities, which highlights the usefulness of the results for coaches for the implementation of training programs and the selection of rowers for best results competition.

A study investigating the effects of a short-term, strength training intervention on 2 000m rowing performance, strength and power development, found that following an intensive period of strength training, rowers better maintained their 2 000m rowing performance (Geel, Caplan, Gribbon, Howatson & Thompson, 2016). Another study conducted by Lawton, Cronin and McGuigan (2013) found that selected oarswomen with comparable anthropometry and 2 000m ergometer ability had greater lower body strength compared to unselected women.

2.4 Prevalence of rowing injuries

Rowers are at risk of developing several types of injuries including lower back, ribs, shoulder, wrist and knee problems during training and competition (Warden, Gutschlag, Wajswelner & Crossley, 2002). The most frequent injury encountered in rowers is low back pain followed by knee injuries (Smoljanovic, Bojanic, Hannafin, Hren, Delimar & Pecina, 2009). It has been noted that rowers have a relatively high frequency (6.1% to 22.6%) of rib stress fractures compared to the general population (Warden et al., 2002). The majority of all rowing injuries are due to overuse. These overuse injuries are normally due to an abrupt change in training volume, alterations in technique or the type of boat rowed (Smoljanovic et al., 2009).

Stutchfield and Coleman (2006) investigated the relationship between lower back pain, hamstring flexibility and lumbar flexion in male rowers. They found that there was no association observed between lower back pain and hamstring flexibility, or between hamstring flexibility and lumbar flexion. Fenwick, Brown and McGill (2009) did a comparison of lumbar spine motion, load, and stiffness on male rowers, they found that asymmetry in thoracic and lumbar muscle activation may result in increased muscle stiffness and pain in the lumbar spine due to overcompensating during training.

The prevalence and incidence of wrist and hand injuries have been shown to be high in rowing (Karlson, 2000; Laura, Kuijer, Kerkhoffs, Maas & Frings-Dresen, 2015). Shoulder pain is also quite common in rowers due to repetitive overload, over-reaching at the catch and due to mechanical injury (Rumball, Lebrun, Di Ciacca & Orlando, 2005), but the literature on this is limited. The patterns of injury are unique in the sport of rowing because of the biomechanics applied in the rowing stroke (Hosea & Hannafin, 2012). It involves a continuous repetitive motion which lays stress on various anatomical areas such as wrist, shoulders, back, pelvic, knees and ankles depending on the rowing stroke phases (Hosea & Hannafin, 2012). Injuries are primarily overuse (Smoljanovic et al., 2009) due to changes in training volume, alteration of rowing techniques and the boat (Hosea & Hannafin, 2012). Back pain may present differently depending on sweep versus sculling while rowers who use both sweep and sculling may lead to the development of wrist injuries. It has been shown that modification in the position in rowing ergometer may lead to knee injuries (Hosea & Hannafin, 2012).

Despite rowing being performed in a seated position with bodyweight supported, there is evidence to suggest that pelvic asymmetry can affect the dynamics of trunk motion while sitting, thus putting the lumbar spine under stress (Al-Eisa, Egan, Deluzio & Wassersug, 2006). Consequently, executing the rowing stroke with asymmetrical lower limb motion may result in a variety of overuse injuries and pain. Although pain is not an area of specific interest in this research, it is important to note that pain or injury may, too, have a significant effect on rowing performance (Donatelli et al., 2012; Wilson, Gissane & McGregor, 2014).

The majority of the research on rowing involved mainly male rowers. Previous research found a high prevalence of lower back pain, knee pain and hip pain in adolescent male rowers (Ng, Campbell, Burnett, Smith & O’Sullivan, 2015). A study by Perea and Ariyasinghe (2016) found that the prevalence of injury in male and female rowers was 68.8% and 57.1%, respectively. Figure 2.2 displays the findings from Perea and Ariyasinghe (2016) on the different types and extent of injuries observed in male and female rowers.

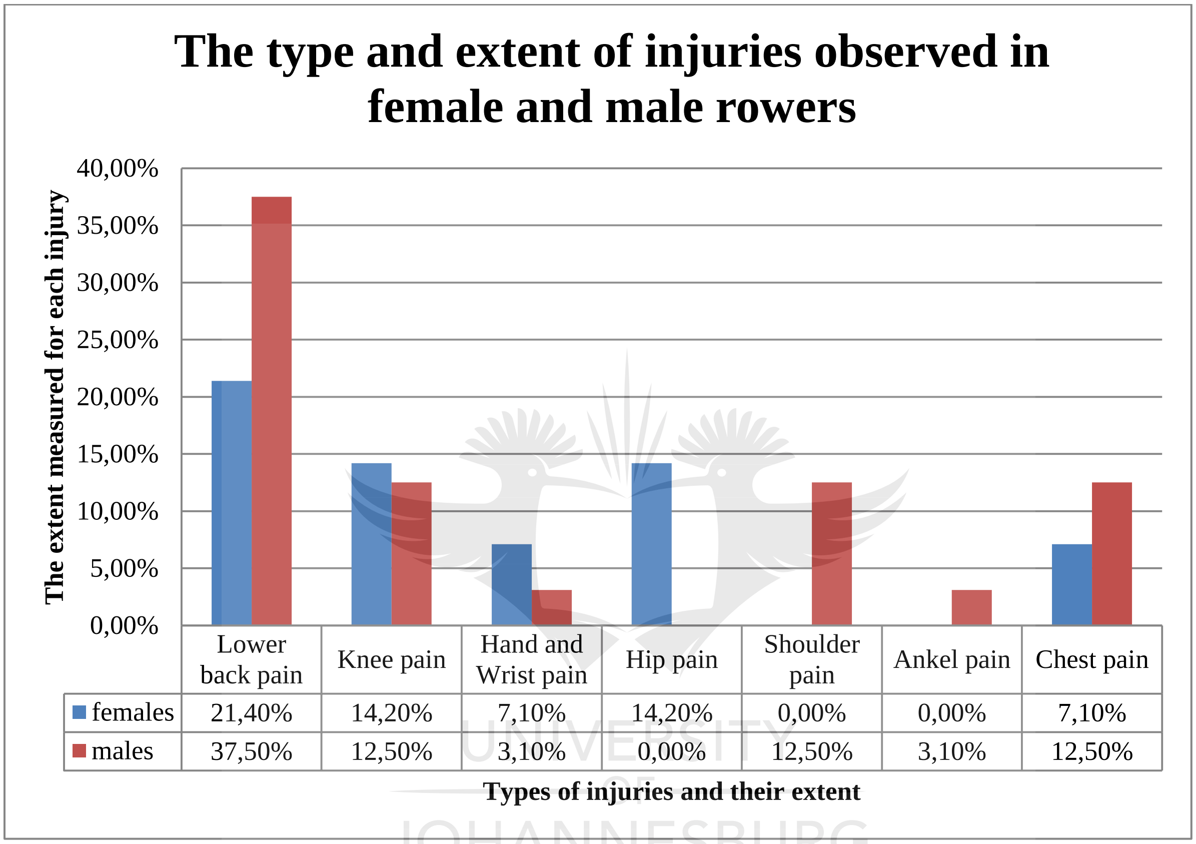

Figure 2.2 The Types and extent of injuries observed in female and male rowers

Previous studies have also looked at how asymmetries of the lower limbs affect power output during ergometer rowing. This research found that ergometer rowing is not symmetrical with respect to lower limb kinematics, and this carries implications for both rowing performance and injuries (Buckeridge et al., 2015; Ruffaldi & Filippeschi, 2012). Shoulder pain in rowers can be the result of overuse, poor technique, or tension in the upper body. The combination most often observed is an anteriorly placed glenohumeral head, a tight posterior shoulder capsule, tight latissimus dorsi and weak rotator cuff muscles (Rumball et al., 2005).

2.5 Isokinetic Testing and Injury Prevention in Rowing

2.5.1 Introduction

There is epidemiological evidence that poor ECC muscular strength and hamstring to quadriceps strength imbalances may play role in traumatic muscle strains (Yeung, Suen & Yeung, 2009). Isokinetic tests can also be used to evaluate magnitude of the ratio of the strength developed during bilateral contraction and the sum of the strength developed by each limb independently (Jakobi & Chilibeck, 2001).

2.5.2 Peak torque and bilateral peak torque deficits

Isokinetic testing provides a precise evaluation of muscle performance and the isokinetic dynamometer is very useful for the comparison between bilateral limb strength and the agonistic and antagonistic relationship during CON muscle contraction. Muscle symmetry is important in kayakers because a balanced stroke produces more stability and a straighter advancing trajectory of the kayak, and imbalances between the limbs indicate a higher risk of injuries (Limonta, Squadrone, Rodano, Marzegan, Veicsteinas, Merati & Sacchi, 2010). Kayakers' main movement responsible for propelling the kayak through the water is the stroke, which is composed of cyclic and repetitive movements of the upper limb and trunk (Lemos, Pranke & Teixeira, 2007). The continuous nature of the sport may cause overload and increase the likelihood of injury (Fiore & Houston, 2001; Fiore, 2003; Hensel, Perroni, Junior & Pinto, 2008).

Rowing may also lead to overuse injuries however, uses mainly the legs and has smaller contributions from the trunk and upper limbs compared to kayaking and therefore, the injury patterns between the two sports may vary (Gonzalez, 2014; Soper & Hume, 2004; Goodall et al., 2012).

Bilateral muscle strength comparison is based on the premise that the strength of bilateral muscle groups should be balanced. If this balance is disturbed, the muscle strength deficit can be associated with increased susceptibility to injury (Dauty, Potiron-Josse & Rochcongar, 2003). Although the relationship between bilateral muscle strength imbalances and an injury incidence is not clear, it has been generally accepted that bilateral imbalances lower than 10% are acceptable (Dauty et al., 2003), whereas a difference higher than 15% is considered a predisposition for injury (Wrigley, 2000). According to Dauty et al. (2003), a bilateral asymmetry between hamstring muscles higher than 10%, warrants strengthening in order to decrease this difference.

Several studies have demonstrated the existence of bilateral deficits in different populations (Howard & Enoka, 1991; Jakobi & Chilibeck, 2001, Simoneau-Buessinger, Leteneur, Toumi, Dessurne, Gabrielli & Barbier, 2015) and age groups (Botton, Radaelli, Wilhelm, Rech, Brown & Pinto, 2016; Kuruganti & Seaman, 2006; Magnus & Farthing, 2008). Another study by Riganas, Vrabas, Papaevangelou and Mandroukas (2010) found that there was a bilateral strength difference in rowers on the limbs that correlate with the oar side which they row on that are also known as their inside limbs (knee/arm). Stroke-side rowers exhibited a significantly higher PTQ value in their inside leg (right) quadriceps and hamstrings at 60°/sec and 180°/sec velocities compared to the outside leg (left). In a respective manner, bow side rowers showed a higher PTQ in their inside leg (left) quadriceps and hamstrings at 60°/sec and 180°/sec compared to the outside leg (right). Furthermore, right hip mobility was found to be significantly higher in stroke side compared to bow side, whereas left hip and ankle mobilities were lower in stroke-side rowers compared to bow side rowers.

Possible causes of bilateral strength deficits include the mechanism of motor neuron activation, limb dominance, previous injuries, and asymmetrical sport-specific training (Beurskens, Gollhofer, Muehlbauer, Cardinale & Granacher, 2015).

Because the muscles of the shoulder joint are stabilizers and enable movement throughout the range of motion, muscle balance is extremely important, both in improving performance and in preventing injuries in athletes (Codine, Bernard, Pocholle & Herrison, 2005; Lugo, Kung & Ma, 2008; Westrick, Duffey, Cameron, Gerber & Owen, 2013). In a previous study done on isokinetic performance of the shoulder's external and internal rotators in adolescent kayakers in the comparison between the dominant limb (DL) and the non-dominant limb (NDL), the results did not demonstrate any statistically significant differences in PTQ, nor in the analysis of the shoulder external/internal rotation ratio (Bonatto, Picolotto, Boff, Zottis, Tadiello & Bonetti, 2017). The shoulder external/internal rotation ratio is important because it reflects muscle function during activity (Yildiz, Aydin, Sekir, Kiralp, Hazneci & Kalyon, 2006).

When considering absolute PTQ in rowers, very little data exists in published literature. However, Lawton, Cronin and McGuigan (2011) reported CON knee extension PTQ values at 60°/sec of 300Nm for elite male rowers and 200Nm for elite female rowers, while Riganas et al. (2010) reported knee extension PTQ values between 217Nm and 286Nm in well-trained, experienced, male rowers at an isokinetic velocity of 60°/sec. Russel et al. (1998) reported CON knee extension PTQ values of 268Nm at 60°/sec, in elite schoolboy rowers. Values for CON knee flexion PTQ are equally scarce, but Riganas et al. (2010) reported values between 113Nm and 132Nm, for male rowers at 60°/sec.

Isokinetic PTQ values for female rowers are even more scarce, but Moody, Malikie and Warren (2009) reported a mean CON knee extension PTQ value of 165Nm at 60°/sec. Relatively little research have been conducted on large numbers of participants for the different shoulder joint movement, thus norms for the shoulder at 60°/sec is limited.

2.5.3 Antagonist-agonist PTQ ratios

The PTQ ratio of the agonist and antagonist knee muscles is associated with the demands of the sport, training adaptations and level of competition (Cheung, Smith & Wong, 2012). Imbalances in the H/Q ratio, as well as significant differences in muscle strength between lower extremities, are important risk factors of injury (Bahr & Krosshaug, 2005; Cumps, Verhagen, Duerinck, Devillé & Duchene, 2008; Hewett, Myer & Zazulak, 2008). Strengthening thigh muscles and H/Q balancing may contribute to reducing the incidence of knee injuries in athletes (Cheung et al., 2012).

Strong hamstrings may have a protective effect against anterior cruciate ligament sprains in females whereas, an increase of quadriceps strength may effectively prevent the development of patellar tendinopathy (Cumps et al., 2008). Croiser, Ganteaume, Binet, Genty and Ferret (2008) reported that imbalances in CON H/Q muscle strength ratio were prevalent among professional soccer players. They also reported that these players (with strength imbalances) were 4-5 times more likely to sustain an injury.

A typical isokinetic CON H/Q ratio for healthy athlete's ranges from 50% to 80%, depending on the angular velocity used (Kong & Burns, 2010). An H/Q ratio based on CON PTQ values has been explored to describe knee-joint stability by Brown, Brughelli, Griffiths and Cronin (2014). They found that intralimb and bilateral limb imbalances can directly affect athletic performance, especially in sports that involve sprinting, changing direction, and kicking. Koutedakis, Frischknecht and Murthy (1997) noted a low H/Q ratio in rowers with low back pain. It has been suggested by Heiser, Weber, Sullivan, Clare and Jacobs (1984) that injury prevention strategies, based on the detection of H/Q imbalances, should aim for an H/Q ratio of 60% at an angular velocity of 60°/sec. Parkin, Nowicky, Rutherford and McGregor (2001) reported a CON H/Q ratio of 55% at an isokinetic velocity of 100°/sec in male rowers, while Koutedakis et al. (1997) reported CON H/Q ratios of 51% in male rowers and 50% in female rowers, at 60°/sec.

Chung, Hahn and Ryu (1987) compared the external and internal shoulder rotation muscle strength values of healthy Korean adults and found that the muscles responsible for internal rotation had higher strength than those responsible for external rotation. The results of Mayer, Horstmann, Röcker, Heitkamp and Dickhuth (1994) indicated that normal ratios of CON shoulder ER/IR for the general population (at 60°/sec), were 57% for the DL and 61% for the NDL. Wang, Macfarlane and Cochrane (2000) measured the shoulder muscle strength of players on the English national volleyball team and found that the ratios of CON shoulder ER/IR were approximately 100% for the DL and 67% for the NDL.

Other studies have investigated the relationship between an imbalance in muscle strength and the occurrence of injuries in rowers. A previous study (Buckeridge, Bull & McGregor, 2014) reported asymmetry in the lower limbs that ranged from 6.8% to 9.7% in healthy elite rowers. Wong, An and Cheung (2015) also reported similar values for lower limb asymmetry (7.1% to 11.4%) in healthy rowers.

2.6. Summary

Rowing has been defined as a sport that requires strength and endurance while challenging both the aerobic and anaerobic energy systems. Training for rowing can cause muscle imbalances and may result in overuse injuries, affecting rowing performance. Isokinetic testing provides a means of assessing muscle strength imbalances and could thus provide valuable information for rowers. Rowing requires a high level of technique and technical understanding. The technique involves almost all muscles of the body, but mainly the use of both legs simultaneously which is used to generate nearly half of the required power. A third of the power during rowing comes from the trunk and only a fifth from the arms. The technical understanding involves the ability to identify the difference in synchronization of upper and lower body muscles.

The rowing stroke begins at the finish where the body is in a straight-legged seated position with the arms closest to the body. The hands move forward and are followed by the body to begin the recovery phase. Once the shoulders and hands have passed a certain point the legs flex until the catch position is reached. The body is in a compressed position with potential energy in the three-body segments needed for the drive phase. The blade is then placed in the water and anchored while the boat moves passed it through efforts applied in the drive phase by the three body segments. The end of the drive phase is the finish and once it has been reached the cycle is then repeated.

Anthropometric characteristics of the physiology of rowers are good performance predictors as studies have shown that successful athletes were heavier, taller, younger rowers who have achieved low BFP, high VO_{2max} values and are involved in individualised high volume training programs with a focus on strength training in the lower body. Studies have shown that rowers are at risk of developing several types of unique injuries due to the biomechanics involving repetitive motion and stress on various anatomical areas applied in the rowing stroke. These injuries are majorly due to overuse in training which can be a result of a specific form of change in training, repetitive load, improper technique, mechanical injury, the form of rowing used and asymmetries in the body.

Studies have also shown that there is a relationship between a muscle strength deficit and an increased risk of injury when there is a disturbance in the balance of the strength of bilateral muscle groups. The possible causes of bilateral strength deficits include the mechanism of motor neuron activation, limb dominance, previous injuries, and asymmetrical sport-specific training. Previous studies have indicated that isokinetic CON H/Q ratios were between 50% and 80% for healthy athletes. Isokinetic testing should thus be used for analysing muscles to improve performance and to prevent injury. However, there is a paucity of CON and ECC isokinetic data in rowers at different levels of performance and in specific countries. Thus, the present study aimed at addressing this in male and female university rowers in the Gauteng province of South Africa.

CHAPTER THREE: METHODOLOGY

3.1 Aims and objectives

The main aim of this study was to assess bilateral isokinetic peak torque (PTQ) in the knee and shoulder joint of university rowers. A secondary aim was to examine possible bilateral muscle imbalances and to compare the males to the females in terms of PTQ produced.

The objectives include determining:

• Bilateral deficits in isokinetic knee flexion and extension PTQ

• Bilateral deficits in isokinetic shoulder external and internal rotation PTQ

• Bilateral isokinetic antagonist-agonist ratios for knee flexion and extension

• Bilateral isokinetic antagonist-agonist ratios for shoulder rotation

Delimitations:

• The current research project did not consider strength deficits in any other joints due to time constraints.

3.2 Research design

The research design used was quantitative, descriptive and comparative in nature.

3.3 Population and sampling

This study used both male and female rowers between the ages of 18 and 35 years. Participants were recruited from university rowing clubs in Gauteng. The universities currently have a combined number of 50 rowers. These rowing clubs are made up of social rower's, i.e. B and C crew athletes and sub-elite rowers who make up the A crew athletes. Both social and sub-elite rowers compete locally and provincially. The elite rowers compete locally, provincially and internationally. This study tested sub-elite rowers as this group of athletes train more often and at higher intensities then the social rowers.

3.3.1 Sample Size and Selection

Participants who adhered to the inclusion and exclusion criteria below and who consented (Appendix A) to take part after reading the information letter (Appendix B) were invited to participate in this study.

3.3.2 Inclusion criteria

The participants complied with the following in order to participate in this research study:

- Participants were required to be older than 18 and younger than 35 years
- Participants must have been a university student
- Participants who have been rowing competitively for at least two years (A crew rowers)
- Must have been injury-free for more than three months
- Passed the PAR-Q.

3.3.3 Exclusion Criteria

Participants were excluded from this research study if they:

- Had been rowing for less than two years (novice or social rowers)
- Were under the age of 18 years or older than 35 years
- Presented with an injury
- Partook in any other sport at a competitive level
- Failed the PAR-Q.

3.4 Testing Methods

Participants were requested to refrain from exercise 24 hours prior to the test and to refrain from eating or rehydrating for three hours prior to the test.

3.4.1 Questionnaire

Each participant completed a Physical Activity Readiness Questionnaire (PAR-Q and You) (Appendix C).

3.4.2 Anthropometric Measurements

Each participant's height/stature (to the nearest mm), body mass (to the nearest kg) and body mass index (BMI in kg/m^2) were assessed using standardized procedures (Heyward & Wagner, 2004).

The MOGAP method was used to calculate body fat percentage (Carter, 1982) from the sum of six skinfolds: triceps, subscapula, supra-iliac, abdomen, thigh and calf (Pescatello, 2014).

3.4.3 Isokinetic Testing

Bilateral knee flexion-extension PTQ and shoulder internal-external rotation PTQ was assessed using the Humac Norm Isokinetic Dynamometer (Humac, 2100 Smith Town Avenue, PO Box 9003, Ronkonkoma, NY, 11779) at 60°/sec using the CON-CON and ECC-ECC contraction modes.

The participants performed a standard warm-up procedure consisting of 10 minutes of light rowing on a Concept2 rowing ergometer (Concept2 Model D, Concept2 Inc, 105 Industrial Park Drive, Morrisville, VT. 05661) at an intensity of 10 to 12 on the Borg rating of perceived exertion (RPE) Scale (Appendix D).

Prior to data collection, the Humac Norm was calibrated according to the manufacturer's instructions. After calibration, the participants were positioned on the isokinetic dynamometer for the assessment of the knee and shoulder maximal strength according to the manufacturer's recommendations. For testing extension and flexion of the knee joint participants were seated with the hip joint at 85° of flexion and attached to the dynamometer chair with Velcro straps in order to provide stability during maximal contractions. The dynamometer's lever arm was fixed with the pad positioned 2.5cm above the lateral malleolus. The axis of rotation of the dynamometer was aligned with the lateral epicondyle of the femur. Each leg was then weighed by the dynamometer to adjust for the effects of gravity (Li et al., 1996). For testing of shoulder internal and external rotation, the participant was supine with the shoulder abducted to 90° and the elbow flexed at 90°. The upper arm was secured by a Velcro strap into a padded V-shaped support pad so that the upper arm was parallel to the floor. The axis of rotation of the dynamometer was aligned with the long axis of the humerus (Yen, 2005).

Each contraction cycle was preceded by five trial/familiarization repetitions at 60°/sec, followed by five maximum effort repetitions at 60°/sec. The participant was allowed a 60-second rest interval between the CON and the ECC protocol (Rosene et al., 2001). A minimum time of two minutes was permitted between the testing of the knee and the shoulder. Verbal encouragement was provided throughout the testing procedure and participants received visual feedback of their performance during the test to motivate them to give maximum effort (Kim & Kramer, 1997). The following isokinetic variables were used for analysis: PTQ measured in Newton-meters (Nm), PTQ divided by body mass (Nm/kg BW), and antagonist/agonist ratios (%). Bilateral comparisons between the DL and the NDL were calculated to assess each participant's bilateral muscle balance for the knee and shoulder joint.

Once participants had completed their test they were taken through a cool-down procedure which consisted of light static stretching of the involved muscles.

Figure 3.1 and 3.2 Examples of the set-up for isokinetic knee extension and flexion

Figure 3.3 Example of isokinetic testing set-up for shoulder internal-external rotation

The 90" abducted position of the glenohumeral joint used for testing shoulder internal-external rotation in this study is similar to the abduction angle used during the finish stage of the rowing stroke. Isokinetic assessment of the shoulder internal and external rotators is dependent based on the work of Hageman, Mason, Rydlund and Humpal (1989), Soderberg and Blaschak (1987), and Walmsley and Szybbo (1987)

3.5 Data analysis

Descriptive statistics (means, minimums, maximums and standard deviations) were used to analyse the data. Means, ranges and standard deviations was used to calculate variance. The Shapiro-Wilk test for normality was used to determine the need for parametric (t-tests) or non-parametric statistics (Mann-Whitney U Tests) (Appendix F). Statistical significance was set at $p<0.05$ (Pallant, 2007).

3.6 ETHICAL CONSIDERATIONS

3.6.1 Principle of respect for autonomy

Participants had the right to full disclosure and the right to self-determination (Dhai & McQoid-Mason, 2011), as participants were given an information letter explaining the requirements of the research prior to participation in the research study. The letter gave full disclosure about the study, allowing them an opportunity to make an informed decision of whether or not to participate (Appendix B). An informed consent was signed by willing participants (Appendix A). Participation in the study was voluntary and participants were free to withdraw at any point without the fear of reprisal.

3.6.2 Principle of non-maleficence (not doing harm)

During this study the researchers had an obligation to protect participants from harm and by not subjecting the participants to any unnecessary discomfort or destress during the research process (Dhai & McQoid-Mason, 2011). The researchers exercised sensitivity and attentiveness throughout the research process by monitoring each participant closely.

3.6.3 Anonymity/confidentiality

This principle ensures that there was confidentiality of the participants' information and privacy and that their information has been locked away safely and destroyed after two years of the data being published (Dhai & McQoid-Mason, 2011). The principle of non-maleficence also ensures that everything was done to prevent harm and injury to the participants during this study.

3.6.4 Principle of justice

The principle of justice consists of the fair treatment of all participants (Dhai & McQoid-Mason, 2011). The participants were free to withdraw from this study at any time without any prejudice, their decision was respected and they were not judged. The expert knowledge of the supervisor guided this study to guarantee the quality of the research process. The researchers conducted this study with honesty and integrity.

Ethical clearance (REC-01-168-2017) was obtained from the Health Science Faculty Research Ethics Committee (Appendix E).

CHAPTER FOUR: RESULTS

4.1 Introduction

The main aim of this study was to assess bilateral isokinetic peak torque (PTQ) in the knee and shoulder joint of university rowers. A secondary aim was to examine possible bilateral muscle imbalances and to compare the males to the females in terms of PTQ produced.

Participants included 24 male and 13 female rowers. The following data will be presented: participant demographics, CON and ECC isokinetic knee flexion and extension PTQ values at 60°/sec, and CON and ECC isokinetic shoulder IR and ER PTQ values at 60°/sec.

4.2 Demographics

Table 4.1 contains the participant demographics. The males and females were of similar age (21.58y vs 21.77y, p=0.936) and BMI (24.58kg/m² vs 24.43kg/m², p=0.667), but they differed significantly in terms of body mass (78.79kg vs 68.85kg, p=0.010), height (179.17cm vs 167.77cm, p=0.000), and BFP (11.25% vs 21.15%, p=0.000). Thus, the male rowers were significantly heavier, taller and had significantly less body fat than the female rowers.

Table 4.1: Demographics for male and female rowers

	Male (n=24)	**Female (n=13)**	**Male vs Female p-value**
	Mean ± SD (range)	Mean ± SD (range)	
Age (y)	21.58 ±2.08 (18-26)	21.77 ±2.28 (19-26)	0.936
Weight (kg)	78.79 ±8.88 (60-97)	68.85 ±12.38 (47-95)	0.010*
Height (cm)	179.17 ±6.70 (164-191)	167.77 ±8.58 (152-189)	0.000*
BMI (kg/m²)	24.58 ±2.62 (20.2-30.0)	24.43 ±3.80 (20.3-34.6)	0.667
BFP (%)	11.25 ±2.89 (7-16)	21.15 ±4.83 (14-30)	0.000*

Skinfolds			
Triceps (mm)	7.88 ±3.37 (3-16)	16.38 ±4.27 (5-22)	0.000*
Sub-scapula (mm)	10.79 ±4.59 (3-19)	17.54 ±6.55 (8-28)	0.004*
Suprailiac (mm)	13.88 ±5.39 (5-22)	18.38 ±7.41 (6-30)	0.084
Abdominal (mm)	16.88 ±5.87 (7-25)	21.31 ±7.81 (12-35)	0.141
Frontal thigh (mm)	19.25 ±5.70 (7-30)	24.85 ±5.46 (17-34)	0.016*
Medial calf (mm)	11.21 ±3.73 (3-16)	15.46 ±2.93 (11-21)	0.003*

***** Statistically significant difference ($p<0.05$)

4.3 CON knee flexion and extension PTQ values at 60°/sec

4.3.1 Males

The mean PTQ for CON knee extension at 60°/sec for males was 207.46 ±45.71Nm for the DL and 194.67 ±42.51Nm for the NDL. Thus there was a significant deficit (10.83 ±7.71Nm; p=0.038) between the DL and the NDL (Table 4.2). The mean PTQ per body weight for CON knee extension at 60°/sec for males differed significantly (p=0.045): 263.75 ±50.32%BW for the DL and 247.71 ±48.02%BW for the NDL.

The mean PTQ for CON knee flexion at 60°/sec for males was 99.46 ±20.73Nm for the DL and 96.96 ±20.65Nm for the NDL. Thus, there was a 14.04 ±9.3Nm (p=0.399) deficit between the DL and the NDL. The mean PTQ per body weight for males' CON knee flexion at 60°/sec had no significant difference (p=0.368): 126.75 ±25.90%BW for the DL and 123.79 ±25.29%BW for the NDL.

The mean H/Q ratio at 60°/sec for males was 48.92 ±10.05% for the DL and 50.38 ±8.02% for the NDL, and the difference was not significant (p=0.435) (Table 4.2).

Table 4.2: CON knee extension and flexion PTQ for males at 60°/sec

	DL (Mean ±SD)	NDL (Mean ±SD)	% diff	p-value
Knee Extension				
PTQ (Nm)	207.46 ±45.71	194.67 ±42.51	6.17	0.038*
PTQ/BW (Nm/kg: %)	263.75 ±50.32	247.71 ±48.02	6.10	0.045*
Knee Flexion				
PTQ (Nm)	99.46 ±20.73	96.96 ±20.65	2.51	0.399
PTQ/BW (Nm/kg: %)	126.75 ±25.90	123.79 ±25.29	2.34	0.368
Antagonist-Agonist Ratio				
H/Q ratio (%)	48.92 ±10.05	50.38 ±8.02	2.90	0.435

*Statistically significant difference ($p<0.05$)

4.3.2 Females

The mean PTQ for CON knee extension at 60°/sec for females was 137.85 ±33.95Nm for the DL and 126.69 ±32.45Nm for the NDL. Thus there was a 12.62 ±11.10Nm (p=0.172) deficit between the DL and the NDL (Table 4.3). The mean PTQ per body weight for CON knee extension at 60°/sec for females showed no significant difference (p=0.161): 199.46 ±35.35%BW for the DL and 183.54 ±33.61%BW for the NDL.

The mean PTQ for CON knee flexion at 60°/sec for females was 61.85 ±24.66Nm for the DL and 63.00 ±20.75Nm for the NDL. Thus, there was a 14.31 ±11.74Nm (p=0.694) deficit between the DL and the NDL (Table 4.3). The mean PTQ per body weight for CON knee flexion at 60°/sec for females had no significant difference (p=0.087): 63.92 ±23.80%BW for the DL and 65.15 ±18.78%BW for the NDL.

The mean H/Q ratio at 60°/sec for females was 44.00 ±10.89% for the DL and 49.54 ±8.21% for the NDL which showed no significant difference (p=0.099) (Table 4.3).

Table 4.3: CON knee extension and flexion PTQ for females at 60°/sec

	DL (Mean ±SD)	NDL (Mean ±SD)	% diff	p-value
Knee Extension				
PTQ (Nm)	137.85 ±33.95	126.69 ±32.45	8.10	0.172
PTQ/BW (Nm/kg: %)	199.46 ±35.35	183.54 ±33.61	7.98	0.161
Knee Flexion				
PTQ (Nm)	61.85 ±24.66	63.00 ±20.75	1.83	0.694
PTQ/BW (Nm/kg: %)	63.92 ±23.80	65.15 ±18.78	1.89	0.087
Antagonist-Agonist Ratio				
H/Q ratio (%)	44.00 ±10.89	49.54 ±8.21	11.18	0.099

*Statistically significant difference (p<0.05)

4.3.3 Males vs females

The percentage strength difference between males and females CON knee extension was 33.6% for the DL and 34.9% for the NDL. Thus there was a significant difference between males and females knee extension PTQ for the DL and the NDL (p=0.000).

The percentage strength difference between males and females CON knee flexion was 37.8% for the DL and 35% for the NDL. Thus there were also significant differences between the males and females knee flexion PTQ for the DL and the NDL (p=0.000). The same trend was observed for PTQ/BW with significant differences between males and females for knee extension and flexion (p=0.000) (Table 4.4).

There was however no significant differences between male and female CON DL and NDL H/Q ratios (p=0.286 & p=0.924).

Table 4.4: CON knee extension and flexion PTQ for males and females at 60°/sec

	Males	Females	% diff. (Males vs Females)	Males vs Females (p-value)
Knee Extension				
DL PTQ (Nm)	207.46 ±45.71	137.85 ±33.95	33.6%	0.000*
NDL PTQ (Nm)	194.67 ±42.51	126.69 ±32.45	34.9%	0.000*
DL PTQ/BW (Nm/kg: %)	263.75 ±50.32	199.46 ±35.35	24.4%	0.000*
NDL PTQ/BW (Nm/kg: %)	247.71 ±48.02	183.54 ±33.61	25.9%	0.000*
Knee Flexion				
DL PTQ (Nm)	99.46 ±20.73	61.85 ±24.66	37.8%	0.000*
NDL PTQ (Nm)	96.96 ±20.65	63.00 ±20.75	35.0%	0.000*
DL PTQ/BW (Nm/kg: %)	126.75 ±25.90	63.92 ±23.80	49.6%	0.001*
NDL PTQ/BW (Nm/kg: %)	123.79 ±25.29	65.15 ±18.78	47.4%	0.000*
Antagonist-Agonist Ratio				
DL H/Q ratio (%)	48.92 ±10.05	44.00 ±10.89	10.1%	0.286
NDL H/Q ratio (%)	50.38 ±8.02	49.54 ±8.21	1.7%	0.924

*Statistically significant difference ($p<0.05$)

4.4 ECC knee flexion and extension PTQ values at 60°/sec

4.4.1 Males

ECC knee extension PTQ for males was 216.67 ±70.99Nm for the DL and 199.50 ±56.38Nm for the NDL. Thus there was a significant deficit 13.38 ±9.02Nm (p=0,001) between the DL and

NDL (Table 4.5). The mean PTQ per body weight for ECC knee extension at 60°/sec for males differed significantly (p=0.000): 286.33 ±68.70%BW for the DL and 253.04 ±63.03%BW for the NDL (Table 4.5).

The mean PTQ for ECC knee flexion at 60°/sec for males was 131.83 ±35.97Nm for the DL and 121.83 ±36.42Nm for the NDL (Table 4.5). Thus, there was an 18.33 ±10.95Nm (p=0.161) deficit between the DL and the NDL. The mean PTQ per body weight for ECC knee flexion at 60°/sec for males had no significant difference (p=0.399): 167.92 ±43.41%BW for the DL and 158.88 ±54.17%BW for the NDL.

The mean H/Q ratio at 60°/sec for males was 59.25 ±10.96% for the DL and 61.79 ±12.57% for the NDL, and the difference was not significant (p=0.317) (Table 4.5).

Table 4.5: Isokinetic ECC knee extension and flexion PTQ for male rowers at 60°/sec

	DL (Mean ±SD)	NDL (Mean ±SD)	% diff	p-value
Knee Extension				
PTQ (Nm)	216.67 ±70.99	199.50 ±56.38	7.92	0.001*
PTQ/BW (Nm/kg: %)	286.33 ±68.70	253.04 ±63.03	11.63	0.000*
Knee Flexion				
PTQ (Nm)	131.83 ±35.97	121.83 ±36.42	7.59	0.161
PTQ/BW (Nm/kg: %)	167.92 ±43.41	158.88 ±54.17	5.38	0.399
Antagonist-Agonist Ratio				
H/Q ratio (%)	59.25 ±10.96	61.79 ±12.57	4.11	0.317

*Statistically significant difference ($p<0.05$)

4.4.2 Females

The mean PTQ for ECC knee extension at 60°/sec for females was 150.15 ±41.75Nm for the DL and 135.85 ±47.06Nm for the NDL. Thus, there was a 16.92 ±11.4Nm (p=0.108) deficit between the DL and the NDL (Table 4.6). The mean PTQ per body weight for ECC knee extension at 60°/sec for females had no significant difference (p=0.087): 217.08 ±42.14%BW for the DL and 196.0 ±54.42%BW for the NDL (Table 4.6).

The mean PTQ for ECC knee flexion at 60°/sec for females was 80.31 ±35.51Nm for the DL and 83.46 ±33.66Nm for the NDL (Table 4.6). Thus, there was an 11.46 ±7.40Nm (p=0.363) deficit between the DL and the NDL. The mean PTQ per body weight for ECC knee flexion at 60°/sec for females had no significant difference (p=0.327): 115.08 ±41.90%BW for the DL and 120.85 ±43.27%BW for the NDL.

The mean for knee ECC H/Q ratio at 60°/sec for females was 52.23 ±12.26% for the DL and 61.77 ±12.26% for the NDL; thus, the difference was significant (p=0.019).

Table 4.6: Isokinetic ECC knee extension and flexion PTQ for female rowers at 60°/sec

	DL (Mean ±SD)	NDL (Mean ±SD)	% diff	p-value
Knee Extension				
PTQ (Nm)	150.15 ±41.75	135.85 ±47.06	9.52	0.108
PTQ/BW (Nm/kg: %)	217.08 ±42.14	196.00 ±54.42	9.71	0.087
Knee Flexion				
PTQ (Nm)	80.31 ±35.51	83.46 ±33.66	3.77	0.363
PTQ/BW (Nm/kg: %)	115.08 ±41.90	120.85 ±43.27	4.77	0.327
Antagonist-Agonist Ratio				
H/Q ratio (%)	52.23 ±12.26	61.77 ±12.26	15.44	0.019*

*Statistically significant difference (p<0.05)

4.4.3 Males vs females

There was statistical significant difference between ECC knee flexion at 60°/sec for males and females (Table 4.7) for the DL and the NDL. The percentage difference between males and females for ECC knee flexion PTQ was 39.1% for the DL (p=0.000) and 31.5% for the NDL (p=0.007). There was also significant difference between ECC knee extension for males and females for the DL and the NDL, with the percentage difference between males and females for ECC knee extension PTQ was 30.7% for the DL (p=0.000) and 31.9% for the NDL (p=0.002).

There was a significant difference of 15.44% observed between the DL and the NDL (p=0.019) for females, this same observation was not seen for the males as there was no significant difference between DL and NDL (p=0.317), the percentage difference was 4.11%. There was also no significant difference found between males and females ECC knee flexion-extension ratio for both DL (p=0.080) and NDL (p=0.556).

Table 4.7: Isokinetic ECC knee extension and flexion PTQ for male and female rowers at 60°/sec

	Males	Females	% Difference (Males vs Females)	Male vs female p-values
Knee Extension				
DL PTQ (Nm)	216.67 ±70.99	150.15 ±41.75	30.7%	0.000*
NDL PTQ (Nm)	199.50 ±56.38	135.85 ±47.06	31.9%	0.002*
DL PTQ/BW (Nm/kg: %)	286.33 ±68.70	217.08 ±42.14	24.2%	0.003*
NDL PTQ/BW (Nm/kg: %)	253.04 ±63.03	196.00 ±54.42	22.5%	0.010*
Knee Flexion				
DL PTQ (Nm)	131.83 ±35.97	80.31 ±35.51	39.1%	0.000*
NDL PTQ (Nm)	121.83 ±36.42	83.46 ±33.66	31.5%	0.007*

DL PTQ/BW (Nm/kg: %)	167.92 ±43.41	115.08 ±41.90	31.5%	0.002*
NDL PTQ/BW (Nm/kg: %)	158.88 ±54.17	120.85 ±43.27	23.9%	0.047*
Antagonist-Agonist Ratio				
DL H/Q ratio (%)	59.25 ±10.96	52.23 ±12.26	11.8%	0.080
NDL H/Q ratio (%)	61.79 ±12.57	61.77 ±12.26	0.03%	0.556

***** Statistically significant difference (p<0.05)

4.5 CON shoulder internal and external rotation at 60°/sec

4.5.1 Males

The mean CON PTQ for shoulder IR at 60°/sec for males was 39.79 ±9.94Nm for the DL and 37.21 ±11.45Nm for the NDL. Thus, there was a 12.38 ±10.40Nm (p=0.071) deficit between the DL and the NDL (Table 4.8). The mean bilateral CON PTQ per body weight for CON shoulder IR for males differed significantly (p=0.048): 51.25 ±12.85%BW for the DL and 47.38 ±13.30%BW for the NDL.

The mean PTQ for CON shoulder ER at 60°/sec for males was 34.04 ±7.45Nm for the DL and 32.08 ±7.82Nm for the NDL (Table 4.8). Thus, there was a 10.75 ±6.47Nm (p=0.008) significant deficit between the DL and the NDL for males. The mean PTQ per body weight for CON shoulder ER at 60°/sec for males had a significant difference (p=0.013): 43.75 ±9.23%BW for the DL and 41.13 ±9.47%BW for the NDL.

The mean for shoulder ER/IR ratio at 60°/sec for males was 87.13 ±13.99% for the DL and 89.17 ±15.44% for the NDL; thus, there was no significant difference (p=0.626) (Table 4.8).

Table 4.8: CON shoulder internal and external rotation at 60°/sec for males

	DL (Mean ±SD)	NDL (Mean ±SD)	% diff	p-value
Internal Rotation				
PTQ (Nm)	39.79 ±9.94	37.21 ±11.45	6.48	0.071
PTQ/BW (Nm/kg: %)	51.25 ±12.85	47.38 ±13.30	7.55	0.048*
External Rotation				
PTQ (Nm)	34.04 ±7.45	32.08 ±7.82	5.76	0.008*
PTQ/BW (Nm/kg: %)	43.75 ±9.23	41.13 ±9.47	5.99	0.013*
Antagonist-Agonist Ratio				
ER/IR ratio (%)	87.13 ±13.99	89.17 ±15.44	2.29	0.626

*Statistically significant difference (p<0.05)

4.5.2 Females

The mean CON PTQ for shoulder IR at 60°/sec for females was 19.77 ±4.71Nm for the DL and 19.54 ±5.44Nm for the NDL. Thus, there was a 13.85 ±12.06Nm (p=0.919) deficit between the DL and the NDL (Table 4.9). The mean bilateral PTQ per body weight for CON shoulder IR at 60°/sec for females showed no significant difference (p=0.958): 28.85 ±5.13%BW for the DL and 28.85 ±7.30%BW for the NDL.

The mean peak torque for CON shoulder ER at 60°/sec for females was 20.23 ±5.15Nm for the DL and 18.69 ±6.13Nm for the NDL (Table 4.9). Thus, there was a 13.15 ±14.07Nm (p=0.210) deficit between the DL and the NDL. The mean peak torque per body weight for CON shoulder ER at 60°/sec for females showed no significant difference (p=0.093): 30.46 ±7.33%BW for the DL and 27.69 ±9.01%BW for the NDL.

The mean shoulder ER/IR ratio at 60°/sec for females was 103.92 ±21.29% for the DL and 95.77 ±15.20% for the NDL; thus, there was no significant difference (p=0.373) (Table 4.9).

Table 4.9: CON shoulder internal and external rotation at 60°/sec for females

	DL (Mean ±SD)	NDL (Mean ±SD)	% diff	p-value
Internal Rotation				
PTQ (Nm)	19.77 ±4.71	19.54 ±5.44	1.16	0.919
PTQ/BW (Nm/kg: %)	28.85 ±5.13	28.85 ±7.30	0	0.958
External Rotation				
PTQ (Nm)	20.23 ±5.15	18.69 ±6.13	7.61	0.210
PTQ/BW (Nm/kg: %)	30.46 ±7.33	27.69 ±9.01	9.09	0.093
Antagonist-Agonist Ratio				
ER/IR ratio (%)	103.92 ±21.29	95.77 ±15.20	7.84	0.373

*Statistically significant difference (p<0.05)

4.5.3 Males vs females

The percentage difference between males and females for CON shoulder IR PTQ was 50.3% for the DL and 47.5% for the NDL. Thus, there was a significant difference between males and females shoulder IR PTQ for DL and NDL (p=0.000) (Table 4.10).

The percentage difference between males and females for CON shoulder ER PTQ was 40.6%% for the DL and 41.7%% for the NDL (Table 4.10). Thus, there were also significant differences between the males and females PTQ for DL and NDL (p=0.000).

The mean CON shoulder ER/IR ratio at 60°/sec for males was 87.13 ±13.99% for the DL and 89.17 ±15.44% for the NDL (p=0.63), and 103.92 ±21.29% for the DL and 95.77 ±15.20% for the NDL in females (p=0.37) (Table 4.10). There was no significant difference between males and females for the NDL ER/IR ratio (p=0.19). However, there was a significant difference between males and females DL IR/ER ratio (p=0.032), with a 16.6% difference between males and females.

Table 4.10: CON shoulder internal and external rotation at 60°/sec for males and females

	Males	Females	% Difference (Males vs Females)	Male vs female p-values
Internal Rotation				
DL PTQ (Nm)	39.79 ±9.94	19.77 ±4.71	50.3%	0.000*
NDL PTQ (Nm)	37.21 ±11.45	19.54 ±5.44	47.5%	0.000*
DL PTQ/BW (Nm/kg: %)	51.25 ±12.85	28.85 ±5.13	43.7%	0.000*
NDL PTQ/BW (Nm/kg: %)	47.38 ±13.30	28.85 ±7.30	39.1%	0.000*
External Rotation				
DL PTQ (Nm)	34.04 ±7.45	20.23 ±5.15	40.6%	0.000*
NDL PTQ (Nm)	32.08 ±7.82	18.69 ±6.13	41.7%	0.000*
DL PTQ/BW (Nm/kg: %)	43.75 ±9.23	30.46 ±7.33	30.4%	0.000*
NDL PTQ/BW (Nm/kg: %)	41.13 ±9.47	27.69 ±9.01	32.7%	0.000*
Antagonist-Agonist Ratio				
DL ER/IR ratio (%)	87.13 ±13.99	103.92 ±21.29	16.6%	0.032*
NDL ER/IR ratio (%)	89.17 ±15.44	95.77 ±15.20	6.9%	0.190

*****Statistically significant difference ($p<0.05$)

4.6 ECC shoulder internal and external rotation at 60°/sec

4.6.1 Males

The mean PTQ for ECC shoulder IR at 60°/sec for males was 49.92 ±12.34Nm for the DL and 43.46 ±11.53Nm for the NDL (Table 4.5). Thus, there was a 14.38 ±11.58Nm ($p=0.001$) deficit between the DL and the NDL. The mean PTQ per body weight for ECC shoulder IR at 60°/sec for males showed a significant difference (p=0.000): 63.79 ±14.82%BW for the DL and 54.96 ±14.06%BW for the NDL.

The mean PTQ for ECC shoulder ER at 60°/sec for males was 39.75 ±9.25Nm for the DL and 37.63 ±9.25Nm for the NDL (Table 4.5). Thus there was a 9.54 ±8.82Nm (p=0.059) deficit between the DL and the NDL. The mean PTQ per body weight for ECC shoulder ER at 60°/sec for males showed a significant difference (p=0.019): 51.38 ±9.38%BW for the DL and 47.75 ±10.04%BW for the NDL.

The mean for shoulder internal and external rotation ECC ratio at 60°/sec for males was 80.21 ±11.43% for the DL and 87.25 ±10.26% for the NDL, thus there was a significant difference (p=0.003) (Table 4.11).

Table 4.11: ECC shoulder internal and external rotation at 60°/sec for males

	DL (Mean ±SD)	NDL (Mean ±SD)	% diff	p-value
Internal Rotation				
PTQ (Nm)	49.92 ±12.34	43.46 ±11.53	12.94	0.001*
PTQ/BW (Nm/kg: %)	63.79 ±14.82	54.96 ±14.06	13.84	0.000*
External Rotation				
PTQ (Nm)	39.75 ±9.25	37.63 ±9.25	5.33	0.059
PTQ/BW (Nm/kg: %)	51.38 ±9.38	47.75 ±10.04	7.07	0.019*
Antagonist-Agonist Ratio				
ER/IR ratio (%)	80.21 ±11.43	87.25 ±10.26	8.07	0.003*

*Statistically significant difference (p<0.05)

4.6.2 Females

The mean PTQ for ECC shoulder IR at 60°/sec for females was 26.62 ±4.57Nm for the DL and 27.15 ±5.89Nm for the NDL (Table 4.12). Thus, there was an 8.31 ±4.66Nm (p=0.304) deficit between the DL and the NDL. The mean PTQ per body weight for ECC shoulder IR at 60°/sec for females showed no significant difference (p=0.372): 36.46 ±7.43%BW for the DL and 40.85 ±10.43%BW for the NDL.

The mean PTQ for ECC shoulder ER at 60°/sec for females was 24.62 ±4.65Nm for the DL and 24.08 ±6.65Nm for the NDL (Table 4.12). Thus, there was a 10.54 ±7.71Nm (p=0.420) deficit between the DL and the NDL. The mean PTQ per body weight for ECC shoulder ER at 60°/sec for females showed no significant difference (p=0.549): 36.46 ±7.43%BW for the DL and 35.77 ±10.85%BW for the NDL.

Shoulder ER/IR ECC ratio at 60°/secs mean value for females was 93.08 ±9.42% for the DL and 88.31 ±13.28% for the NDL, thus there was no significant difference(p=0.0.54) (Table 4.12).

Table 4.12: ECC shoulder internal and external rotation at 60°/sec for females

	DL (Mean ±SD)	NDL (Mean ±SD)	% diff	p-value
Internal Rotation				
PTQ (Nm)	26.62 ±4.57	27.15 ±5.89	1.95	0.304
PTQ/BW (Nm/kg: %)	36.46 ±7.43	40.85 ±10.43	10.75	0.372
External Rotation				
PTQ (Nm)	24.62 ±4.65	24.08 ±6.65	2.19	0.420
PTQ/BW (Nm/kg: %)	36.46 ±7.43	35.77 ±10.85	1.89	0.549
Antagonist-Agonist Ratio				
ER/IR ratio (%)	93.08 ±9.42	88.31 ±13.28	5.12	0.054

*Statistically significant difference (p<0.05)

4.6.3 Males vs females

The percentage difference between males and females ECC shoulder IR was 46.7% for the DL and 37.5% for the NDL. Thus, there was a significant difference between males and females IR PTQ for the DL and the NDL (p=0.000) (Table 4.13).

The percentage difference between males and females ECC shoulder ER was 38.1% for the DL and 36% for the NDL. Thus, there was also a significant difference between males and females ER PTQ for the DL and the NDL (p=0.000) (Table 4.13).

The mean ECC shoulder ER/IR ratio at 60°/sec for males was 80.21 ±11.43% for the DL and 87.25 ±10.26% for the NDL (p=0.003) (Table 4.13) and was 93.08 ±9.42% for the DL and 88.31 ±13.28% for the NDL for females (p=0.05).There was significant difference in the ER/IR ratio for males (p=0.003) and no significant difference for females (p=0.054). However there was significant difference in DL IR/ER ratio between males and females (p=0.002) with a 13.8 % difference between males and females.

Table 4.13: ECC Shoulder internal and external rotation at 60°/sec for males and females

	Males	Females	% Difference (Males vs Females)	Male vs female p-values
Internal Rotation				
DL PTQ (Nm)	49.92 ±12.34	26.62 ±4.57	46.7%	0.000*
NDL PTQ (Nm)	43.46 ±11.53	27.15 ±5.89	37.5%	0.000*
DL PTQ/BW (Nm/kg: %)	63.79 ±14.82	36.46 ±7.43	42.8	0.000*
NDL PTQ/BW (Nm/kg: %)	54.96 ±14.06	40.85 ±10.43	25.7%	0.003*

External Rotation				
DL PTQ (Nm)	39.75 ±9.25	24.62 ±4.65	38.1%	0.000*
NDL PTQ (Nm)	37.63 ±9.25	24.08 ±6.65	36%	0.000*
DL PTQ/BW (Nm/kg: %)	51.38 ±9.38	36.46 ±7.43	29%	0.000*
NDL PTQ/BW (Nm/kg: %)	47.75 ±10.04	35.77 ±10.85	25.1%	0.003*
Antagonist-Agonist Ratio				
DL ER/IR ratio (%)	80.21 ±11.43	93.08 ±9.42	13.8%	0.002*
NDL ER/IR ratio (%)	87.25 ±10.26	88.31 ±13.28	1.2%	0.949

*****Statistically significant difference ($p<0.05$)

This study found bilateral PTQ deficits in both the knee and shoulder muscles for male and female rowers. However, the male rowers showed larger strength deficits when compared to the females.

CHAPTER FIVE: DISCUSSION

5.1 Introduction

This chapter will discuss the results presented in chapter four. This chapter also explores the possible link between the literature that has been presented in Chapter Two and the results obtained in the present study. The aim of the present study was to assess bilateral isokinetic peak torque (PTQ) in the knee and shoulder joint of university rowers. A secondary aim was to examine possible bilateral muscle imbalances and to compare the males to the females in terms of PTQ produced.

5.2 Demographics

The average age of Olympic rowers normally varies between 20 and 24 years; the rowers from the present study's ages (21.58 for males and 21.77 for females) corresponded with those of previous research (Akça, 2014). Since rowing is such a demanding sport, both physically and mentally, it is understandable that the top international rowers are relatively young.

When compared to the height of international rowers, the participants of the current study had an average height which compared to those of less successful rowers, with both the males and females being shorter than successful international or Olympic rowers. A similar trend was observed for weight with the current study participants' weight being less than that of successful international rowers (DeRose et al., 1989; Mikulic, 2009; Secher et al., 1983). Taller rowers possess longer strokes which may assist them in rowing faster than shorter rowers. Swimmers in sprint events exhibit a similar tendency, with successful elite international swimmers being taller than less successful swimmers (Kjendlie & Stallman, 2011). The current study's BFP values for male (11.25%) and female rowers (21.15%) are slightly higher than the BFP reported previously, since Hagerman and Toma (1997) reported that male international rowers had a range of BFP values from 6% to 10%, and Sklad, Krawezyk and Majle (1994) reported that female rowers and kayakers a BFP range of 16% to 19%.

5.3 CON and ECC isokinetic PTQ values for knee extension and flexion at 60°/sec

5.3.1 CON knee extension-flexion PTQ at 60°/sec

A previous study (Buckeridge et al., 2014) reported mean asymmetry in lower limbs ranging from 6.8% to 9.7% in healthy elite rowers during ergometer rowing. Wong et al. (2015) also reported a similar range of figures (7.1% to 11.4%) in healthy rowers. The present study's mean CON knee extension and flexion PTQ values for male rowers were lower when compared to previous studies (Lawton, Cronin & McGuigan, 2011; Riganas et al., 2010). For example, Lawton et al. (2011) reported a mean CON knee extension PTQ value of 300Nm for male rowers, compared to the present study's range of 195Nm (NDL) to 208Nm (DL). Riganas et al. (2010) previously reported knee extension PTQ values between 217Nm and 286Nm in well-trained, experienced, male rowers, while Russel et al. (1998) reported knee extension PTQ values of 268Nm in elite schoolboy rowers, at an isokinetic velocity of 60°/sec.

Riganas et al. (2010) reported knee flexion PTQ values between 113Nm and 132Nm for male rowers at 60°/sec; this is slightly higher compared to the current study's male rowers whose knee flexion PTQ values ranged between 97Nm (NDL) and 99Nm (DL). Thus, the current study's male rowers displayed lower CON knee extension and flexion PTQ values than that reported previously for international male rowers.

In addition, the present study established that the mean CON PTQ values of male rowers' knee extensors for the DL were significantly higher (6%) than the NDL. This finding is supported by the results from Riganas et al. (2010), who also identified bilateral strength differences in rowers. This muscular imbalance or asymmetry could be attributed to leg dominance, however the possibility exists that these differences may also relate to the sport of rowing and its unique training demands.

The same trend was not found in the current study's female rowers for either knee extension or flexion. Thus, there were no significant bilateral knee muscle imbalances found in the female rowers from the current study. However, the current study's female rowers also displayed smaller CON knee extensor PTQ values at 60°/sec (NDL: 127Nm & DL: 138Nm), compared to the 200Nm reported by Lawton et al. (2011) and the 165Nm reported by Moody et al. (2009).

The findings from the present study identified significant strength deficits between male and female rowers in the current study. The female rowers produced significantly lower PTQ values across all CON actions measured compared to the male rowers. These findings are in accordance with those of previous studies (Keenan, Senefeld & Hunter, 2018; Gillies & Bell, 2000; Hunter, 2014).

5.3.2 ECC knee extension-flexion PTQ at 60°/sec

The male rowers ECC knee extension PTQ values for in the current study were higher than the CON PTQ in the DL (ECC>CON: 4.4%) and in the NDL (ECC>CON: 2.5%), which correlate to a previous study done by Parkin et al. (2001), who found that oarsmen were significantly stronger in ECC knee extension compared to CON knee extension. The current study also established that there was a significant difference of ±8% ($p=0.001$) in ECC knee extension PTQ at 60°/sec between the two limbs (DL>NDL).

The mean ECC knee flexion PTQ values in the present study were similar to the findings of Parkin et al. (2001) who reported that there were no significant differences between the two limbs in the male rowers. However, ECC knee flexion PTQ was higher than CON knee flexion PTQ in the DL (ECC>CON: 24.6%) and in the NDL (ECC>CON: 20.4%).

The ECC knee extension PTQ values in female rowers were greater than the CON PTQ in the DL (ECC>CON: 8.2%) and the NDL (ECC>CON: 6.7%); this follows the trend of the males in the current study and the male rowers in the Parkin et al. (2001) study. The CON and ECC knee extension and flexion PTQ values obtained in this study were generally smaller than the rowers studied by Janiak et al. (1993) and Kornecki et al. (2010). However, it is difficult to compare the current study's findings to theirs, as both Janiak et al. (1993) and Kornecki et al. (2010) combined the male and female rowers. The sequence of muscle groups in terms of the force developed was however similar, where knee extension PTQ was higher than knee flexion PTQ. The female rowers' knee extension PTQ values were higher than the values generated by team game players in volleyball (Xaverova, Dirnberger, Lehnert, Belka, Wagner & Orechovska, 2015). However, a deeper analysis of the participants' characteristics revealed that these players were taller and heavier, which confirms the relation between the PTQ developed and the body mass. The current study also found a ±10% strength difference between the females DL and NDL ECC knee extensors (DL>NDL), which were greater than the strength difference found in the study of Xaverova et al. (2015). This bilateral strength deficit could be caused by the demands of sweep rowing and the different training styles linked to different sports.

A similar pattern was seen for female ECC knee flexion mean PTQ values with the ECC PTQ values being greater than the CON PTQ values in the DL (ECC>CON: 22.9%) and in the NDL (ECC>CON: 24.5%). The female rowers' ECC knee flexion PTQ values had a similar pattern to the female participants in Xaverova et al. (2015) study, but were substantially lower. This substantial difference could be due to the participants in Xaverova et al. (2015) study being taller and heavier than the female rowers in the current study and the different training styles affecting performance outcomes. The previous study conducted by Xaverova et al. (2015) however did highlight a need for particular strengthening to compensate for muscle overload, because ECC strength is an important indicator of safe functional and sport-specific task execution (Dauty et al., 2003). Indicating that, the rowers in the current study may be at risk of injuries due to higher bilateral strength deficits.

The comparison between the ECC and CON knee extension PTQ showed that both males and females' DL and NDL displayed less than a 10% difference (ECC>CON). However, the comparison of the ECC and CON knee flexor PTQ revealed a strength difference that was greater than 20% for both males and females' DL and NDL (ECC>CON). This could indicate that the hamstring muscles work eccentrically more than concentrically during the rowing stroke. Introducing more concentric- and eccentric-specific training may thus help increase both CON and ECC power output, resulting in stronger and faster rowers.

Bilateral muscle strength comparison is based on the premise that the strength of compared muscle groups should be balanced. If this balance is disturbed, the muscle strength deficit incidence may be associated with increased susceptibility to injury in the lower limbs (Dauty et al., 2003). The relationship between bilateral muscle strength imbalances and an injury incidence is not clear. According to Dauty et al. (2003), bilateral asymmetry higher than 10% in hamstring muscles should be addressed.

The present study found greater ECC knee flexion in the male's DL and female's NDL, but both had a similar pattern in their ECC knee extensors (DL>NDL). In addition, the current study found a ±8% and ±4% difference between DL and NDL ECC knee flexion PTQ in males and females, respectively. These percentage differences show that the males had a greater bilateral strength difference than the females, revealing that the male rowers could be at a higher risk of injury than the female rowers. Koutedakis et al. (1997) support this as they attributed the role of the hamstrings in controlling the pelvis, suggesting that powerful quadriceps muscles combined with weak hamstrings could alter the rotation of the pelvis during the stroke, altering the lumbar-pelvic rhythm and forcing the athlete to gain reach and power from the lumbar spine.

5.3.3 Hamstring/Quadriceps PTQ ratios at 60°/sec

The typical isokinetic CON H/Q ratio for healthy male and female athletes ranges from 50% to 80% depending on the angular velocity used during assessment (Kong & Burns, 2010; Koutedakis et al., 1997; Parkin et al., 2001). The H/Q ratio based on CON PTQ values has been explored by several researchers and a CON H/Q ratio of 60%, at an angular velocity of 60°/sec, has been suggested for knee injury prevention purposes (Brown et al., 2014; Heiser et al., 1984). Previous studies by Karlson (1998) and Koutedakis et al. (1997) investigated the relationship between muscle imbalance and the occurrence of injuries in scullers and sweep rowers. Koutedakis et al. (1997) noted a low H/Q ratio of 51% for the males and 50% for the females, suggesting weakness of the hamstring muscle group in rowers with lower back pain. They suggested that a low H/Q ratio might interfere with the lumbo–pelvic rhythm, leading to increased stress on the lumbar spine. The causes of such imbalances in rowers are not yet known, but could be due to the nature of rowing.

The present study's male rowers had similar CON PTQ H/Q ratios of 49% (DL) and 50% (NDL), which were comparable with the values previously reported in the literature. However, the female rowers had a lower H/Q ratio in the DL (44%) than that of previously reported studies, but the NDL had a H/Q ratio of 50%. However, this difference of 11% between the DL and the NDL H/Q ratio was not significant. Since rowing doesn't require ballistic knee joint movements like running or jumping, these values, although slightly low, should not predispose them to knee injury. However, these relatively low H/Q ratios may increase the risk of back injuries in rowers, as previously reported (Koutedakis et al., 1997).

The male rowers from the present study had similar ECC PTQ H/Q ratios of 59% (DL) and 62%, while the female rowers had significantly different H/Q ratios of 52% (DL) and 62% (NDL). The ECC H/Q ratios were also greater than the CON H/Q ratio in males (DL ECC>CON 17.4% & NDL ECC>CON 18.5%) and females (DL ECC>CON 15.8% & NDL ECC>CON 19.8%). The difference between CON and ECC knee muscle PTQ has previously been reported (Dauty et al., 2003) and is supported by Huxley's sliding filament theory (Huxley, 1957; Huxley & Simmons, 1971).

5.4 Shoulder internal-external rotation at 60°/sec

5.4.1 CON shoulder internal-external rotation PTQ at 60°/sec

In the present study, the male rower's CON shoulder ER and IR PTQ values showed a ±6% (DL>NDL) strength difference. This was similar to a previous study done by Bonatto et al. (2017) on male adolescent kayakers who also had a strength difference with the DL being stronger than the NDL (DL>NDL).

The mean CON IR PTQ values identified in the present study for the females were very similar in the DL and NDL, with there being ±1% strength difference (DL>NDL). There was, however, a ±8% strength difference (DL>NDL) for the females' ER PTQ values. This could be due to the non-oarside hand having a longer lever and at the start of the drive draws tangentially stronger than the oarside hand (Mattes, Schaffert, Manzer & Bohmert, 2015). In addition, the current studies' findings were supported by the findings of similar PTQ values for CON IR and ER in female kayakers where their DL was greater than their NDL (Bonatto et al., 2017). Thus, rowing coaches should encourage their rowers to alternate between their dominant and non-dominant side when rowing sweep-oar. This will help reduce strength deficits and improve the rower's abilities' to row on both stroke side and bow side, making them more competitive athletes in the sport.

The findings of the current study show that the males were stronger than the females in both IR (DL ±50% & NDL ±48%) and ER (DL ±41% & NDL ±42%). However, the females showed less percentage difference between the DL and NDL which shows that there were greater strength deficits found in the males than in the females.

5.4.2 ECC shoulder internal-external rotation PTQ at 60°/sec

There was a significant weakness of approximately 13% in the NDL compared to the DL for ECC shoulder IR PTQ in the present study's male rowers. The normal difference contributed to upper limb dominance is reported to be approximately 10% (Dauty et al., 2003) and thus, some of this difference could be attributed to normal limb dominance. However, a similar pattern for ER PTQ values was not observed as there was ±5% ($p=0.059$) difference (DL>NDL). This showed that there was a strength deficit in the male rowers IR, but not in their ER. This could be due to the greater demand put on the external rotator cuff muscles during the rowing stroke (Flood & Simpson, 2012).

The findings of the present study did not show a similar trend for the ECC females IR and ER PTQ values as there were no strength deficits. However, when IR was adjusted to BW (Nm/kg:%) there was ±11% strength deficit found (NDL>DL). This could be a result of the asymmetrical demands of sweep rowing on the rotator cuff muscles.

The males and females ECC IR PTQ values in the present study were higher than their ER PTQ values which were supported by similar findings on previous study (Aginsky, 2016; Ruas, Pinto, Cadore & Brown, 2015). The weaker ER muscles compared to the IR muscles can prove athletes are at risk of injury as a superior translation of the humeral head can lead to a narrowing of the subacromial space and predisposition to rotator cuff impingement (van Cingel, Kleinrensink & Mulder, 2007).

The present study showed that the males had substantially higher ECC ER and IR PTQ values than females which was to be expected due to the males having greater physiological characteristics such as height, weight and muscle mass. The study also showed that the males (DL>NDL) had greater differences in their ER and IR PTQ values than those in females which can show that there was more of a bilateral strength deficit found in males than in females.

5.4.3 Shoulder external/internal rotation PTQ ratios at 60°/sec

Bahr et al. (2005) indicated that muscle imbalance may cause damage to the joints. Based on this, it is possible to say that rowers are at risk of injury due to having unbalanced ER to IR ratios which were associated with a higher risk of injury. Chung et al. (1987) compared the ER and IR muscle strengths of healthy Korean adults and found that the muscles responsible for IR had higher strength than those responsible for ER. The results of Mayer et al. (1994) indicated that normal ratios of ER to IR strengths for the general population for 60°/sec testing were 57% for the DL and 61% for the NDL in a CON test. Wang et al. (2000) measured the shoulder muscle strength of players on the English national volleyball team and found that the ratio of the strength of the external rotator to that of the internal rotator muscle was approximately 100% for the DL and 67% for the NDL in a CON test.

The difference identified was not significant in the males CON IR/ER ratio (NDL>DL) in the present study, however, their ECC IR/ER ratio did differ significantly by ±8% (p=0.003). The current study also found that the female's CON and ECC IR/ER ratio values showed no significant difference but their CON values were greater than their ECC.

The findings of the present study show that the CON IR/ER ratios were higher in the females and differed significantly from the males by ±17% (p=0.032). The ECC findings showed that the females also had higher IR/ER ratio values than the males with a significant difference of 14% (p=0.002), this could have been due to the females having less bilateral strength deficits when compared to the males. As well as the limitation of there being fewer female participants than male participants, this could have skewered the results.

5.5 Summary

The main aim of this study was to assess bilateral isokinetic PTQ in the knee and shoulder joint of male and female university rowers. This is one of the first studies in South Africa to establish reference values for isokinetic PTQ values in the knee and shoulder for university rowers. The results of the present study may however also be useful to rowers and rowing coaches from other countries. A secondary aim was to examine possible bilateral muscle imbalances and to compare the males to the females in terms of PTQ produced.

The present study found selected, significant bilateral strength differences in both CON and ECC knee extension PTQ values between the DL and the NDL, in the male rowers. Both males and females exhibited higher CON knee PTQ values in their DL flexors and extensors compared to the NDL. The males and females also had greater PTQ values in their DL for ECC knee extension. However, the same trend was not observed for ECC knee flexion with the male's DL and the female's NDL indicating greater PTQ values on average. For ECC and CON isokinetic knee flexion and extension ratios, the NDL ratio was greater than the DL ratio for both males and females.

This current study also showed ECC contractions to be greater than CON contractions, with both males and females having less than 10% (ECC>CON) difference in their knee extensors and a greater than 20% (ECC>CON) difference in their knee flexors.

The females in this study showed no significant difference between the DL and NDL for shoulder isokinetic CON PTQ of ER and IR. However, there was significant difference observed for the DL and NDL in males for ER. Both male and female rowers showed ECC ER PTQ values lower than the IR muscles, while the females showed greater shoulder DL and NDL IR/ER ratios in both CON and ECC contractions compared to the males.

5.6 Limitations and recommendations for future research

The small sample size (n=37) was a limitation; however, rowing is a relatively small sport in South Africa and thus, the results of the present study will provide valuable reference values for CON and ECC isokinetic PTQ for the knee and shoulder muscles in South African university rowers. Using a larger group sample (>50) may produce greater statistical power. In addition, including both elite and sub-elite rowers may also be valuable to differentiate between the performances characteristics at these different levels, as well as including amount of hours the athletes train per week.

Another limitation was the limited speed of isokinetic testing used to measure PTQ. Future research should perhaps investigate isokinetic testing at higher speeds. The present study utilised open kinetic chain isokinetic movement patterns during testing. Rowing involves multi-joint, closed kinetic chain movements in the lower limb and multi-joint, open kinetic chain movements in the upper limb and thus, the validity of using isolated, single-joint isokinetic testing in rowers, especially for the lower limb, is a possible limitation. Including other biomechanical components like posture, flexibility, endurance and power output could also provide additional information on rowing performance and the risk of injury. Lastly, an analysis of the difference between rowing stroke between stroke side and bow side, as well as sculling, could be done.

CHAPTER SIX: CONCLUSION

The main aim of this study was to assess bilateral isokinetic peak torque (PTQ) in the knee and shoulder joint muscles of university rowers. A secondary aim was to examine possible bilateral muscle imbalances in these two joints and to compare the males to the females in terms of PTQ produced.

This is one of the first studies to establish reference values for isokinetic PTQ in the knee and shoulder muscles for university rowers. In addition, the results highlight the presence of bilateral muscle imbalances and antagonist/agonist imbalances in both male and female rowers for CON and ECC knee flexion and extension, as well as for shoulder IR and ER. Overall, female rowers showed less muscle imbalances than the male rowers. The presence of muscle imbalances may predispose rowers to overuse injuries and the results of the current study may thus assist the rowing fraternity to prevent and reduce these injuries. The reduction of muscle imbalances may also increase rowing performance. The results of the present study may thus be useful to rowers, rowing coaches, sport scientists, biokineticists and sports medicine practitioners.

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APPENDIX A: CONSENT FORM

UNIVERSITY OF JOHANNESBURG

DEPARTMENT OF SPORT AND MOVEMENT STUDIES

RESEARCH CONSENT FORM

Assessing Isokinetic Peak Torque of the Knee and Shoulder in Adult Rowers

Please initial each box below:

☐ I confirm that I have read and understand the information letter dated 2017 for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

☐ I understand that my participation is voluntary and that I am free to withdraw from this study at any time without giving any reason and without any consequences to me.

☐ I agree to take part in the above study.

______________________	______________________________	______________
Name of Participant	Signature of Participant	Date
______________________	______________________________	______________
Name of Researcher	Signature of Researcher	Date

APPENDIX B: INFORMATION LETTER

UNIVERSITY
OF
JOHANNESBURG

DEPARTMENT OF SPORT AND MOVEMENT STUDIES RESEARCH STUDY INFORMATION LETTER

Isokinetic Peak Torque Values of the Knee and Shoulder in University Rowers

Good Day

My name is Kirsten Nolan, I WOULD LIKE TO INVITE YOU TO PARTICIPATE in a research study on bilateral strength deficits in adult rowers.

Before you decide on whether to participate, I would like to explain to you why the research is being done and what it will involve for you. I will go through the information letter with you and answer any questions you have. This should take about 5 minutes. The study is part of a research project being completed as a requirement for a Master's Degree in Biokinetics through the University of Johannesburg.

THE PURPOSE OF THIS STUDY is to assess isokinetic peak torque of knee and shoulder in university male and female rowers.

Below, I have compiled a set of questions and answers that I believe will assist you in understanding the relevant details of participation in this research study. Please read through these. If you have any further questions I will be happy to answer them for you.

DO I HAVE TO TAKE PART? No, you don’t have to. It is up to you to decide to participate in the study. I will describe the study and go through this information sheet. If you agree to take part, I will then ask you to sign a consent form.

WHAT EXACTLY WILL I BE EXPECTED TO DO IF I AGREE TO PARTICIPATE? Firstly, you will complete an injury history and a physical activity readiness (PAR-Q and You) questionnaire to ensure that you are able to safely take part, once you are cleared to take part, your height, weight and knee and shoulder muscle strength will be assessed using a computerised machine (Humac Norm Isokinetic Dynamometer). This testing will take up about two hours of your time. The testing will require you to exercise, so please note that if you agree to participate, please come dressed appropriately (men: shorts, T-shirt and running shoes; ladies: shorts, T-shirt, tank top and running shoes). Also please remember to bring along a towel and dry clothes as you may want to shower afterwards.

WHAT WILL HAPPEN IF I WANT TO WITHDRAW FROM THE STUDY? If you decide to participate, you are free to withdraw your consent at any time without giving a reason and without any consequences. If you wish to withdraw your consent, please inform me as soon as possible.

IF I CHOOSE TO PARTICIPATE, WILL THERE BE ANY EXPENSES FOR ME, OR PAYMENT DUE TO ME: You will not be paid to participate in this study and you will not bear any expenses.

RISKS INVOLVED IN PARTICIPATION: If you qualify to participate in this study, you may experience some discomfort during and after the strength testing as these tests can lead to muscle soreness and muscle stiffness (especially the two days after your test). This exercise-induced muscle soreness and stiffness is a normal reaction after maximum effort exercise and you should not worry about it and you also don’t need to get any medicine for it as it will disappear in 24 to 48 hours.

BENEFITS INVOLVED IN PARTICIPATION: You may benefit from the knowledge obtained from the study in terms of muscle strength and strength deficits. This may enable you to improve your rowing performance or by elimination possible risk factors for overuse injury by addressing your identified weaknesses or areas of improvement.

WILL MY PARTICIPATION IN THIS STUDY BE KEPT CONFIDENTIAL? Yes. No names or other identifying information will appear on any of the questionnaires or raw data sheets. All data and backups thereof will be kept in password protected folders and-or locked away as applicable. Only I and my research supervisor will be authorised to access your anonymised information in connection with this research study.

WHAT WILL HAPPEN TO THE RESULTS OF THE RESEARCH STUDY? The results will be written into a research report that will be assessed by external examiners. In some cases, results may also be published in a scientific journal or presented at an academic conference. In either case, you will not be identifiable in any documents, reports or publications. You will be given access to the final study results if you would like to see them.

WHO HAS REVIEWED AND APPROVED THIS STUDY? Before this study was allowed to start, it was reviewed in order to protect your interests. This review was done first by the Department of Sport and Movements Studies, and secondly by the Faculty of Health Sciences Research Ethics Committee at the University of Johannesburg. In both cases, the study was approved.

WHAT IF THERE IS A PROBLEM? If you have any concerns or complaints about this research study, its procedures or risks and benefits, you should ask me. You may also contact me at any time if you feel you have any concerns about being a part of this study. My contact details are:

Kirsten.nolan076@gmail.com

083 201 1567

FURTHER INFORMATION AND CONTACT DETAILS: Should you wish to have more specific information about this research project, have any questions, concerns or complaints about this research study, its procedures, risks and benefits, you can communicate with my supervisor or the chair of the Faculty of Health Sciences Research Ethics Committee using the contact details given below.

Supervisor: Prof L. Lategan

E-mail: leonl@uj.ac.za

Tel: 011 559 6966 (W)

Chair Faculty of Health Sciences Research Ethics Committee: Prof C. Stein

E-mail:cstein@uj.ac.za

Tel: 011 559 6564 (W)

APPENDIX C: PAR-Q & You (Pescatello, 2014)

Participant number**:_____**

Physical Activity Readiness Questionnaire (PAR-Q & You)

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
☐	☐	**1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	**2. Do you feel pain in your chest when you do physical activity?**
☐	☐	**3. In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	**4. Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	**5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	**6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	**7. Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ______________________________

SIGNATURE ______________________________ DATE ______________________________

SIGNATURE OF PARENT ______________________________ WITNESS ______________________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

continued on other side...

APPENDIX D: BORG RPE SCALE (Pescatello, 2014)

Borg Rating of Perceived Exertion

6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

APPENDIX E: University of Johannesburg Research Ethics Committee number

UNIVERSITY OF JOHANNESBURG

FACULTY OF HEALTH SCIENCES

RESEARCH ETHICS COMMITTEE
NHREC Registration no: REC-241112-035

REC-01-168- 2017

4 April 2018

TO WHOM IT MAY CONCERN:

STUDENT:	**NOLAN, K**
STUDENT NUMBER:	**201381835**
TITLE OF RESEARCH PROJECT:	Isokinetic Peak Torque Values of the Knee and Shoulder in University Rowers
DEPARTMENT OR PROGRAMME:	**SPORT AND MOVEMENT STUDIES**
SUPERVISOR: Prof L Lategan	**CO-SUPERVISOR:** -

The Faculty Research Ethics Committee has scrutinised your research proposal and confirm that it complies with the approved ethical standards of the Faculty of Health Sciences; University of Johannesburg.

The REC would like to extend their best wishes to you with your postgraduate studies.

Yours sincerely,

Prof C Stein
Chair : Faculty of Health Sciences REC
Tel: 011 559 6564
Email: cstein@uj.ac.za

APPENDIX F: Shapiro-Wilk test for normality

The Shapiro-Wilk test was used as there were less than 50 participants in each group (Pallant, 2007). Testing for normality provided the necessary information that was used to decide which tests were used for further analysis of the data. If "$p \geq 0.05$", this would indicate that there was a normal distribution and parametric tests were used. If "$p < 0.05$", this indicated that the data was not normally distributed and non-parametric tests were used.

Table: Shapiro-Wilk test results for normality and corresponding p-value.

	Group	Shapiro-Wilk test statistics	p-value
CON Knee Ext PTQ at 60°/sec DL	Male	0.974	0.761
	Female	0.920	0.247
CON Knee Flex PTQ at 60°/sec DL	Male	0.957	0.388
	Female	0.946	0.533
CON Knee Ext PTQ at 60°/sec NDL	Male	0.966	0.566
	Female	0.929	0.330
CON Knee Flex PTQ at 60°/sec NDL	Male	0.970	0.661
	Female	0.954	0.655
CON Knee Ext PTQ at 60°/sec DL BW%	Male	0.966	0.574
	Female	0.885	0.084
CON Knee Flex PTQ at 60°/sec DL BW%	Male	0.958	0.403
	Female	0.981	0.986
CON Knee Ext PTQ at 60°/sec NDL BW%	Male	0.961	0.467
	Female	0.933	0.371
CON Knee Flex PTQ at 60°/sec NDL BW%	Male	0.963	0.502
	Female	0.955	0.677
CON Knee PTQ ratio at 60°/sec DL	Male	0.972	0.724
	Female	0.952	0.624
CON Knee PTQ ratio at 60°/sec NDL	Male	0.987	0.985
	Female	0.966	0.848
ECC Knee Ext PTQ at 60°/sec DL	Male	0.936	0.136
	Female	0.969	0.887

ECC Knee Flex PTQ at 60°/sec PTQ DL	Male	0.933	0.115
	Female	0.935	0.391
ECC Knee Ext PTQ at 60°/sec NDL	Male	0.897	0.018
	Female	0.948	0.563
ECC Knee Flex PTQ at 60°/sec NDL	Male	0.937	0.143
	Female	0.976	0.955
ECC Knee Ext PTQ at 60°/sec DL BW%	Male	0.881	0.009
	Female	0.950	0.594
ECC Knee Flex PTQ at 60°/sec PTQ DL BW%	Male	0.944	0.201
	Female	0.922	0.265
ECC Knee Ext PTQ at 60°/sec NDL BW%	Male	0.917	0.050
	Female	0.967	0.850
ECC Knee Flex PTQ at 60°/sec NDL BW%	Male	0.889	0.013
	Female	0.926	0.299
ECC Knee PTQ ratio at 60°/sec DL	Male	0.960	0.430
	Female	0.879	0.069
ECC Knee PTQ ratio at 60°/sec NDL	Male	0.923	0.069
	Female	0.817	0.011
Shoulder rotation			
Shoulder CON PTQ IR at 60°/sec DL	Male	0.916	0.046
	Female	0.934	0.380
Shoulder CON PTQ ER at 60°/sec DL	Male	0.965	0.556
	Female	0.941	0.467
Shoulder CON PTQ IR at 60°/ sec NDL	Male	0.951	0.283
	Female	0.877	0.066
Shoulder CON PTQ ER at 60°/sec NDL	Male	0.935	0.124
	Female	0.938	0.433
Shoulder CON PTQ IR at 60°/sec DL BW%	Male	0.953	0.314
	Female	0.933	0.370
Shoulder CON PTQ ER at 60°/sec DL BW%	Male	0.951	0.291
	Female	0.784	0.004
Shoulder CON PTQ IR at 60/ sec NDL BW%	Male	0.960	0.438
	Female	0.963	0.800
Shoulder CON PTQ IR at 60°/sec NDL BW%	Male	0.934	0.118
	Female	0.943	0.496
Shoulder CON PTQ ER/IR	Male	0.987	0.985

ratio at 60°/sec DL	Female	0.858	0.036
Shoulder CON PTQ ER/IR ratio at 60°/sec NDL	Male	0.973	0.731
	Female	0.935	0.395
Shoulder ECC PTQ IR at 60°/sec DL	Male	0.958	0.400
	Female	0.932	0.359
Shoulder ECC PTQ ER at 60°/sec DL	Male	0.943	0.187
	Female	0.895	0.113
Shoulder ECC PTQ IR at 60°/sec NDL	Male	0.962	0.480
	Female	0.892	0.103
Shoulder ECC PTQ ER at 60°/sec NDL	Male	0.937	0.141
	Female	0.846	0.025
Shoulder ECC PTQ IR at 60°/sec DL BW%	Male	0.949	0.252
	Female	0.933	0.368
Shoulder ECC PTQ ER at 60°/sec DL BW%	Male	0.952	0.300
	Female	0.930	0.345
Shoulder ECC PTQ IR at 60°/sec NDL BW%	Male	0.959	0.415
	Female	0.936	0.406
Shoulder ECC PTQ ER at 60°/sec NDL BW%	Male	0.954	0.331
	Female	0.940	0.451
Shoulder ECC PTQ ER/IR ratio at 60°/sec DL	Male	0.928	0.086
	Female	0.967	0.857
Shoulder ECC PTQ ER/IR ratio at 60°/sec NDL	Male	0.952	0.303
	Female	0.947	0.554

APPENDIX G: Humac Norm Calibration Report

HUMAC2015 Calibration Report

Date	Calibration	Type	ConvFact	Dir	Result	Machine	Therapist	Verify 1	Verify 2	Small	Big	Baseline	Adapter	Dyna	Side
2018/05/25	No	Torque		1		NORM		41.04	149.97	2470	9026		Yes	0	0
2018/05/25	No	Torque		0		NORM		41.00	150.03	2464	9017		Yes	0	0
2018/05/25	Yes	Torque	0.01661	1	PASS	NORM				0	9028		Yes	0	0
2018/05/25	Yes	Torque	0.01664	0	PASS	NORM				0	9015		Yes	0	0
2018/04/17	No	Torque		1		NORM	LEON	40.96	149.97	2472	9050		Yes	0	0
2018/04/17	No	Torque		0		NORM	LEON	41.02	150.02	2474	9048		Yes	0	0
2018/04/17	Yes	Torque	0.01658	0	PASS	NORM	LEON			0	9047		Yes	0	0
2018/04/17	Yes	Torque	0.01657	1	PASS	NORM	LEON			0	9052		Yes	0	0
2017/11/09	No	Torque		1		NORM	CSMi Tech	40.96	150.03	2472	9054		Yes	0	0